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THE OSTEOLOGY OF *EMBOLOPHORUS DOLLOVIANUS*, COPE, WITH AN ATTEMPTED RESTORATION.

THE Pelycosaurian fauna of the Permian beds of Texas has been described from fragmentary material in very large measure, from fragments of the skull, from isolated portions of the vertebral column, and from separate limb bones; rarely is any large portion of one animal found preserved. The result has been the almost inevitable description of different portions of the skeleton of forms belonging to the same genus and species under different names. This fact has been very apparent in the attempt to locate the correct taxonomic position of the very complete specimen described below, but at the same time it has made apparent the compactness and coherence of the family *Clepsydropsidae* in a most striking manner.

In the collection of the University of Chicago is a specimen, No. 114, of a Pelycosaurian in which a very large portion of the skeleton is represented, warranting an attempt at a description of the complete osteology. The bones were incased in the peculiarly refractory cement of iron and sand which is common on the bones in this locality, and this has rendered the preparation of the skeleton and its study a matter of long time. The specimen was discovered in slightly inclined strata with the head downward and the tail exposed, so the forequarters and skull were well preserved.

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The type genus and species, *Embolophorus fritillus*, was described in 1878[1] as follows:

This form reposes on some dorsal vertebræ with intercentra and ribs in place, which display some interesting characters. The neural arch is co-ossified, and the zygapophyses and diapophyses are well developed; the latter not elongate, and standing on the base of the neural arch. The centra are notochordal. The intercentra are narrowed and transversely elongate. The ribs are two-headed; the capitulum is received into a fossa on the posterior border of the intercentrum in advance of the vertebra which supports the diapophysis, to which the tuberculum is attached.

The curious mode of articulation I have not observed in the species of the genera heretofore described, unless the forms of some of the intercentra of *Clepsydrops limbatus* indicate it. If so, that species must be removed to *Embolophorus*.

Char. spef.—Centra with circular section at all points and contracted in at the middle. No carinæ or grooves. The intercentra project beyond the edges of the centra, giving the column the appearance of supporting annular ridges. Their lateral angles extend upward nearly to the base of the neural arch. The diapophyses are short and directed upward and forward; their extremities are concave. The zygapophyses are large and their faces are nearly hortizontal. The size of this species is small, little exceeding that of *Bolosaurus striatus*.

MEASUREMENTS.

Length of a centrum with an intercentrum attached		0.0056[m]
Length of a centrum		0.0040
Diameter of a centrum,	vertical	0.0035
	horizontal	0.0035
Expanse of diapohyses		0.0080
Expanse of heads of rib		0.0035
Elevation to summit of neural canal		0.0045

Later, in 1884,[2] Cope described other features of *Embolophorus*:

The articulation of the ribs in Embolophorus.—The ribs of the Theromorpha are two-headed. While the tubercular articulation has the usual position at the extremity of the diapophysis, the capitular is not distinctly, or is but partially indicated, on the anterior edge of the centrum, in Clepsydrops and Dimetrodon. In Embolophorus, as I showed in 1869 [misprint for 1878], the capitular articulation is distinctly to the intercentrum. A second and larger species of that genus, recently come to hand, displays this character in

[1] "Description of Extinct Batrachia and Reptilia from the Permian Formation of Texas," *Proc. Am. Phil. Soc.*, Vol. XVII, pp. 518, 519.

[2] "Fifth Contribution to the Knowledge of the Fauna of the Permian Formation of Texas and the Indian Territory," *ibid.*, Vol. XXII, p. 43.

a striking degree, since the intercentrum possesses on each side a short process with a concave articular facet for the head of the ribs. From the slight corresponding contact with the intercentrum seen in Dimetrodon and the other genera, there can be little doubt that this is the true homology of the ribs in the Theromorpha.

These remarks were accompanied by a figure of the vertebra of *Embolophorus*, but no name was given to the new genus.

In 1886,[1] the name *E. dollovianus* is proposed for this last species without further description.

In 1890,[2] Lydekker lists this genus as present in the collections of the British Museum and presents figures of dorsal vertebræ. The specific name is respelled as *dolloverianus*.

From a careful comparison of the type material now preserved in the American Museum of Natural History in New York city, it seems to me that there is little doubt that the species *E. dollovianus* is very much closer to the genus *Dimetrodon* than to the type of *Embolophorus*, and that it must eventually be placed there where the material is better known.

The specimen described below is nearly anatomically complete, the only parts lacking being the ribs, the posterior foot, and the ends of the dorsal spines, with, probably, a few dorsal vertebræ. The right side of the skull is nearly perfect as far back as the posterior edge of the orbit, and the bones are preserved in their natural relations; the weak temporal arches are destroyed, but the articular portion of the suspensorium with the faces for the lower jaw attachment are preserved. The basicranium is separate, as in most specimens of the *Pelycosauria*, but both this and the greater part of the lower jaws are preserved. The bones of the palatal region are badly disturbed and flattened against the inner side of those of the facial region, so that their position cannot be made out further than that they were much as in the specimen of *Dimetrodon* previously described by the author (1). The bones of the shoulder girdle, the clavicles, and the inter-clavicle, a complete fore-limb with the fore foot, of the

[1] "Systematic Catalogue of Species of Vertebrata Found in the Beds of the Permian Epoch in North America, with Notes and Descriptions," *ibid.*, Vol. XVI.

[2] "*Catalogue of the Fossil Reptilia and Amphibia in the British Museum*, Part IV, pp. 109, 110.

left side with part of the fore limb of the right side, the pelvis nearly perfect on both sides, and parts of the bones of the posterior limb are all preserved. Thirty-five vertebræ, beginning with the atlas and terminating with several caudals, represent the vertebral column; it is possible that the column is not complete, but, considering the series and comparing it with Cope's published figure of the vertebral column of the *Dimetrodon*[1] it seems that only the end of the tail and possibly a few anterior dorsals are missing. The figure given by Cope shows the column complete to the second sacral. The dependent portion figured as a part of the attached pelvis on one of the vertebræ is the rib of the first sacral, such as is shown in Figs. 20 and 21, but covered by a portion of the matrix. The peculiar shortening of the lumbar vertebræ is evidently just beginning. There are twenty-five presacrals figured by Cope, but there is a break between the twentieth and twenty-first; there are twenty-seven in the present specimen. From the seeming necessity of proportions and because of the uncertainty as to the correct number, I have added four vertebræ in the anterior dorsal region, making the total thirty-two. This may be too many. The numbers given to the vertebræ in the following descriptions are such as indicate their position in the accompanying restoration, and are arbitrary in that the vertebræ were not all discovered in series, but have been located by their anatomical peculiarities. Beginning with the seventh presacral, the series is complete and was found in position to the second caudal.

The skull.—The individual bones of the skull show such slight differences from the bones of the skull of *Dimetrodon incisivus* already described by the author (1) that it is unnecessary to repeat the descriptions. In Fig. 1 is given a side view of the skull, showing the bones in their natural positions; the bones are so slender and the matrix so hard that it has been impossible to remove it all from the bones; in consequence the drawings have been made somewhat diagrammatic, but this has been done only so far as necessary to eliminate the matrix; the relative positions of the bones, and even their distortion, has been pre-

[1] *Proc. Am. Phil. Soc.*, August, 1880, Figs. 3 and 3*a*, Pl. VI.

served. The skull is broken on the mid-line, and the top, which was originally quite flat, has been turned up so that the bones appear in the same plane as the bones of the face. The prominent outer process of the pterygoid bone, which abuts against the inner side of the lower jaw, appears at the lower posterior angle of the skull, and to its posterior edge is attached the articular bone of the lower jaw in an inverted position. The lower jaw

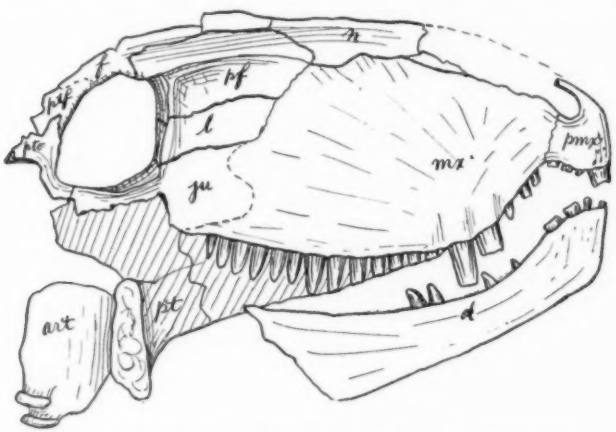


FIG. 1.—Anterior portion of the skull; left side. ⅓ natural size.

is distinct from the mass containing the skull, but in the figure is placed in the correct position.

Noticeable is the large size of the orbit, with its prominent border all around, and its elevated position at the posterior angle of the skull. There is but a single large canine tooth in the upper jaw where *Dimetrodon* has two, but this is, perhaps, of no great taxonomic value, as in forms with successional teeth it is very possible that one may be lost before the other is far enough developed to appear. Neglecting this difference, the number of teeth in the upper jaw is the same (seventeen) in both genera. In Fig. 2 is shown a restoration of the skull of the *Pelycosauria* published in 1899 (1). A comparison with Fig. 1 will show that this restoration is in all essentials correct, at least as regards the side and top. Such structures of the base of the

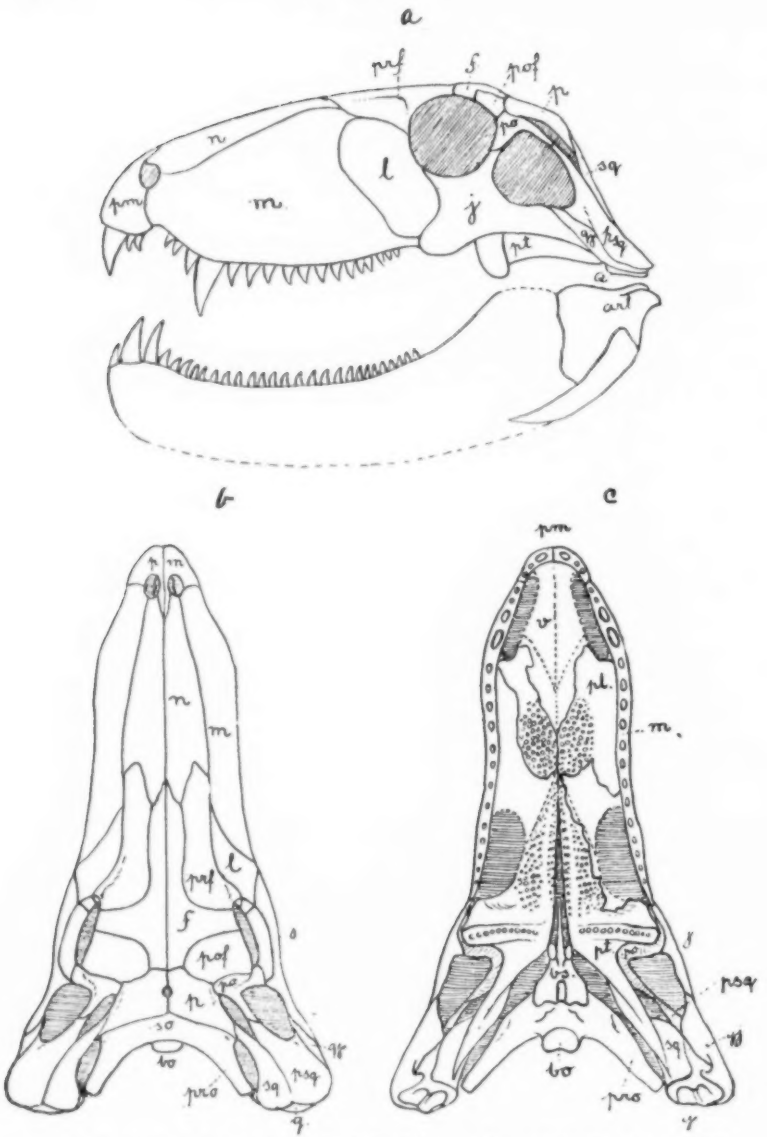


FIG. 2.—Restoration of the skull of the Pelycosauria; *a*, from the side; *b*, from above; *c*, from below.

skull as are preserved also go to show the correctness of the restoration. The basi-cranium is separate from the rest of the skull and shows but few differences from the basi-sphenoid and basi-occipital figured in the description of *Dimetrodon* (1), Pl. I, Figs. 11-14. The bones are somewhat smaller and a little broader in proportion than in *Dimetrodon*.

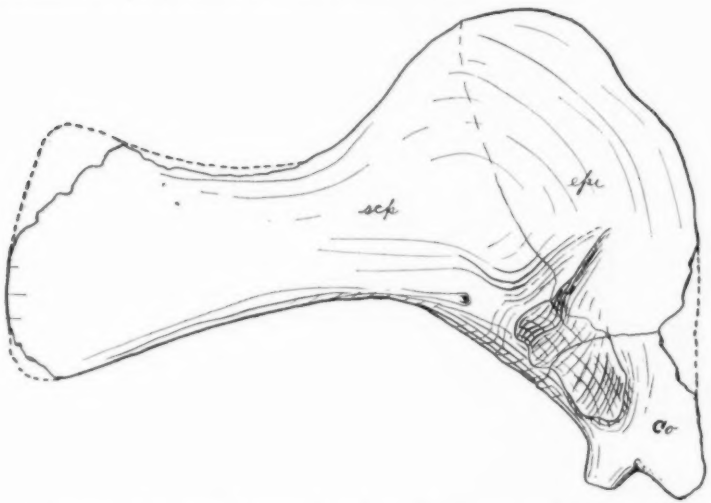


FIG. 3.—United scapula, coracoid, and epicoracoid, *scp*, scapula; *co*, coracoid *epi*, epicoracoid. ⅓ natural size.

MEASUREMENTS OF THE SKULL.

Length of skull from anterior end of nose to posterior edge of orbit	0.225[m]
Height from just back of last tooth to top of skull	0.080
Antero-posterior and vertical diameters of orbit	0.050
Greatest height of side of skull	0.100

The shoulder girdle.—The left side of the shoulder girdle is preserved almost without distortion, so that it is possible to make out the natural curvature of the structure. In Fig. 3 are shown the united scapula, coracoid, and epicoracoid; the true length of the scapula is not shown because of the foreshortening due to the curvature, but in Fig. 4 are shown the scapula and

epicoracoid in profile, showing the true length and the curvature. The coracoid remains free from the scapula through life, but the suture between the scapula and epicoracoid is closed near the outer edges of the bones. The posterior (upper) edge of the cotyloid cavity is formed by a very strong ridge or process of bone which extends out somewhat, upon the epicoracoid. At the base of this ridge the epicoracoid is perforated by a large foramen, and just posterior to the ridge the shaft of the scapula is penetrated obliquely from behind forward by a somewhat smaller foramen. The epicoracoid is very thin, and the greater portion of the scapula is also thin and expanded, but the region near the cotyloid cavity is thicker and very strong.

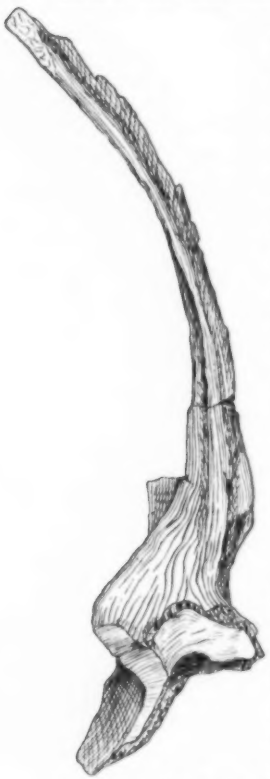


FIG. 4.—Side view of the scapula and epicoracoid. ⅓ natural size.

MEASUREMENTS OF THE SHOULDER GIRDLE.

Length of the scapula - -	0.330–40[m]
Width across the scapula and epicoracoid opposite the cotyloid cavity	0.120

The clavicle lies in nearly the natural position on the scapula and epicoracoids. It is a peculiarly shaped bone, with the inner ends much expanded and very thin, and the inner edge almost straight. The distal ends are very slender and rod-like and contract to a point which is marked with strong striations. Near the middle of the posterior edge is a rugose process for ligamentous attachment. Fig. 5 shows the clavicle of the right side.

The interclavicle is less well preserved than the other bones of the shoulder girdle, but the size and form are easily made out. There is a long and slender median process which projected posteriorly and is well preserved; the anterior end was thinner and much expanded; the edges are broken, but by

comparison with the figure of the interclavicle published by Cope (2), Pl. III, Fig. 5, it would seem that there were strong radial processes. The length of the bone was about 0.31–32^{m}, and the width of the expanded exterior end about 0.120^{m}.

In Fig. 6 is shown in diagrammatic manner the shoulder girdle with bones in their proper positions.

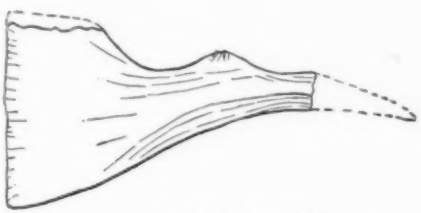


FIG. 5.—Clavicle of the right side, lower view. ⅓ natural size.

The fore limb.—The humerus and radius conform very closely in size and shape with the same bones of *Dimetrodon;* see (1), Pl. III, Figs. 32 and 33. The ulna is represented by the proximal end only, but this is quite different from the ulna of *Dimetrodon.* Compare Fig. 7 with (1), Pl. III, Figs. 34 and 35. The olecranon fossa is more widely open,

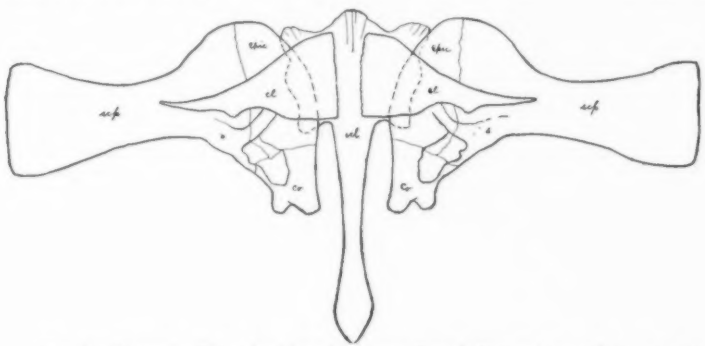


FIG. 6.—Diagram of the shoulder girdle seen from below, *scp*, scapula; *co*, coracoid; *epi*, epicoracoid; *cl*, clavicle; *inte*, interclavicle.

and the whole bone is more clumsy and less finely moulded—a remark which may apply to all the bones of the skeleton in a general way.

Length of the humerus - - - - - - - -	0.191^{m}
Width lower end humerus - - - - - - - -	0.103

The front foot of the left side is nearly perfectly preserved,

a few of the phalanges only being lost. Unfortunately the bones were not all preserved in position, so that it is impossible to give the position of all the elements with certainty; the bones of uncertain position are those marked carpals 3, 4 and 5, and *centrale* and digits 3, 4 and 5. The other bones and digits 1 and 2 are in the position in which they were found, which is seemingly the correct one. Most notable is the small size of the first digit and its possible wide diversion from the other digits in life. It lies attached to the side of the metacarpal of the second digit and turned at right angles to the other digits, so that it appears in profile when the others are seen from the top or bottom. All the digits terminate in claws of relatively great size, and that of the reduced first digit is as large or larger, absolutely, than those of the other digits. There must have been considerable cartilage in the carpus, for, although the bones have been separated and carefully cleaned, it is impossible to articulate the elements with any accuracy. Fig. 8 shows the most probable position of the bones.

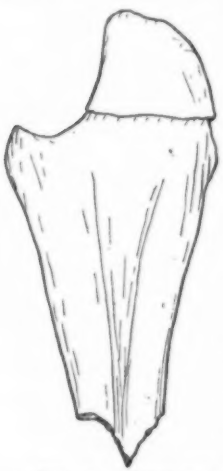


FIG. 7.—Upper portion of the ulna of the left side. ⅔ natural size.

The pelvic girdle.—The pelvis is nearly perfect. The two sides are preserved, so that the missing parts of one side are supplied by the other. The only point of uncertainty is the exact shape of the thin lower edges of the ischium and portions of the edges of the pubis and ilium. As shown in Fig. 9, the three bones meet in the acetabular cavity and are separate through life. The ilium ends anteriorly in an abrupt elevated crest and posteriorly is continued as a slender rod. The ischium is a broad and very thin plate, nearly semicircular in outline; the bones of the two sides evidently met in a ventral symphasis. The acetabular edge of the ischium is very strong and prominent, and looks rather forward and upward than straight upward. This is similar to the condition found in the *Crocodilia* and other

forms where the belly is carried very low between the legs. The pubis lies nearly parallel to the axis of the body.

MEASUREMENTS OF THE PELVIS.

Greatest length of ilium	0.150[m]
Length articular face in the cotyloid cavity	0.061
Width articular face in the cotyloid cavity	0.040
Greatest length of the pubis	0.121
Length of distal edge of the ischium	0.155

The posterior limb.—The posterior limb is represented by the distal end of the femur and the proximal end of the tibia. The femur is very badly preserved. The whole outer shell of bone is scaled off so that what remains is practically a cast of the interior cavity and of the cancelous tissue of the condyles; but it appears that it is very different from the femur of *Dimetrodon*, (1) Pl. III, Figs. 36 and 37. The condyles are less well separated and lie both near the distal end of the bone instead of one at the side; the whole appearance is of a lower type.

From all appearances of the skeleton the posterior portion of the animal seems to have been somewhat weaker than the anterior.

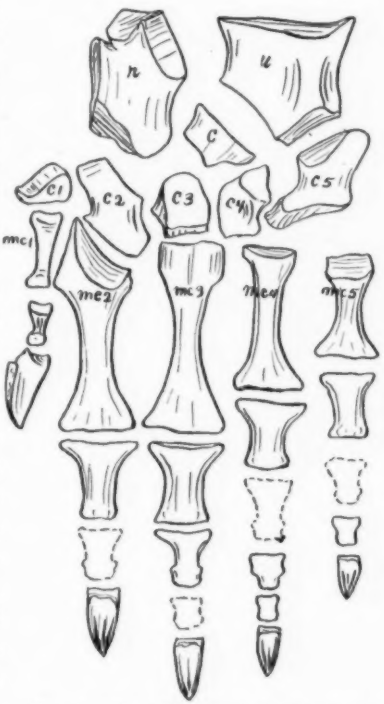


FIG. 8.—Front foot from the upper surface. ⅔ natural size. *r*, radiale; *u*, ulnare; *c*, centrale; *1–5*, carpals one to five; *mc–mc 5*, metacarpals one to five. ⅔ natural size.

The vertebral column.—The most notable feature in the skeleton is the wide diversity in the form of the elements of the vertebral column. In the cervicals and lumbars the neural

arch is co-ossified with the centrum and in the dorsals it is free. The ribs of the cervicals and anterior dorsals are united by the tuberculum to the transverse process and by the capitulum to a process of the preceding intercentrum, but in the lumbars, caudals, and posterior dorsals there is no process on the intercentrum for the capitulum of the rib which is attached to edge of the centrum. The intercentra change remarkably through the series; in the anterior portion of the column they have

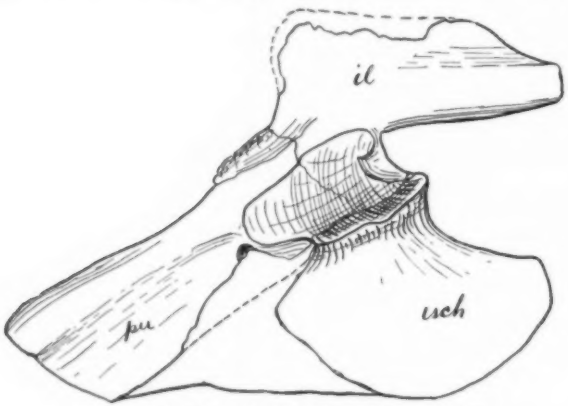


FIG. 9.—Pelvis from the left side. ⅓ natural size.

considerable vertical height and prominent lateral processes for the capitula of the ribs; in the posterior part of the series they become shallower and wider in an antero-posterior direction and lose all trace of the process for the ribs in the lumbars and even in the posterior dorsals (?). In the cervicals, the dorsals, and the anterior caudals there is a prominent facet on the lower portion of the anterior face of the centrum for attachment of the intercentrum. This is absent on the lumbars and sacrals. The anterior and posterior zygapophyses change from broad in the cervicals to narrow in the dorsals, and broad in the lumbars and caudals again; in the same order the articular faces of the zygapophyses change from horizontal to oblique and back to horizontal, so that the faces of the post-zygapophyses of the dorsals look out as well as downward, and of the pre-

zygapophyses in as well as up. The bottom line of the centrum in the cervicals and dorsals has a prominent and very thin keel, while this is absent in the posterior lumbars and the sacrals. All these are characters which have been used to define different genera and species, and their union in one form goes to show how close are the different genera of the family *Clepsydropsidae* and how difficult it is to identify forms from isolated vertebræ.

The atlas.—The first cervical is represented by a centrum only; there was probably a very rudimentary and loosely attached neural arch which has disappeared. The first intercentrum,

a *b* *c*

FIG. 10.—*a*, second intercentrum from below; *b*, same from the anterior face; *c* an intercentrum from the posterior portion of the dorsal series. Natural size.

between the atlas and condyle, is not preserved. That such an element did exist is shown by its presence in *Dimetrodon* (1), Pl. II, Fig. 20. The second intercentrum, between atlas and axis, is large and presents a deeply concave face for the posterior face of the atlas. On either side of the intercentrum are strong posteriorly projecting processes for articulation with the cervical rib. In the collection of the University of Chicago there are specimens of the atlas of *Pelycosauria* with the pre-atlas inter centrum strongly attached to the atlas by co-ossification (Fig. 10 *a* and *b*).

MEASUREMENTS OF THE SECOND INTERCENTRUM.

Greatest breadth - - - - - - - - - -	0.027 m
Antero-posterior length on mid-line of lower surface - -	0.012

The *axis* (Fig. 11) has a strong neural spine, with considerable antero-posterior extent; in the last respect it differs quite markedly from *Dimetrodon* where the spine is rather thick and not expanded in the antero-posterior diameter to such an extent,

(1) Pl. II, Fig. 20. The posterior edge of the spine is much thicker than the anterior and is quite flat; the upper end shows a broad surface, smooth and slightly concave, probably for ligmentous attachment. On the anterior edge there are two small areas very similar to the one on the top of the spine. The anterior edge of the neural spine overlapped the centrum of the atlas so that the zygapophyses at the point of contact were weak, if developed at all. There is no trace of the sutural connection between the spine and the neural arch, though such a connection did undoubtedly exist in the youth of the animal. There is no pronounced keel on the lower surface of the centrum, but the whole body of the vertebræ slants obliquely backward, so that the posterior face of the centrum is much lower than the anterior. The transverse process is attached to the base of the neural arch and the upper portion of the centrum; it curves sharply outward and downward. The distal end of the transverse process is lost, but it evidently reached as far down as the lower line of the centrum. The post-zygapophyses are well developed, and the articular faces are horizontal; the region of the pre-zygapophyses is somewhat injured, but enough remains to show that the processes, if present, were small. The upper half of the centrum only, is occupied by the notochordal canal, so that the notochordal funnel of the anterior face occupies the upper portion of the face, the lower half of the face is occupied by the facet for the intercentrum; this is shown in profile in the figure.

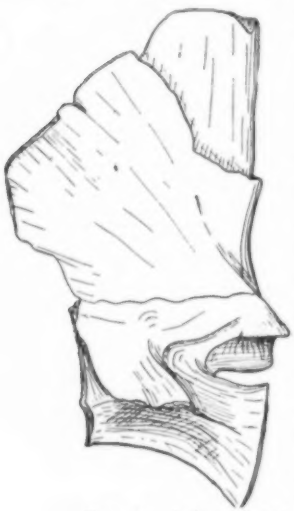
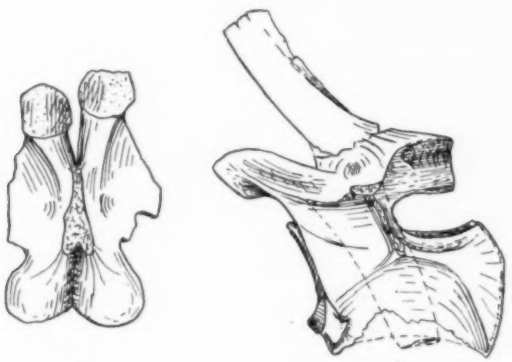


FIG. 11.—Axis. ⅔ natural size.

MEASUREMENTS OF AXIS.

Length along bottom line of centrum	0.038 m
Distance from top of spine to lower line of the posterior face of the centrum	0.113
Greatest width of spine	0.054
Width of the posterior zygapophyses	0.032

The spine of the *third cervical* (Fig. 12) is quite slender and, though incomplete at the upper end, was evidently quite short. The spine is curved forward, so that it lay close to the spine of the axis, and its base is quite narrow, as it is sharply pinched in by a deep fossa on each side. The anterior and posterior zygapophyses are well developed, and the faces are nearly horizontal, so that in the natural condition of the bone they looked straight up and down. The transverse process was attached to the base of the neural spine and to a ridge rising from the upper portion



a *b*

FIG. 12.—Third cervical. *a*, from above; *b*, from the side. ⅔ natural size.

of the centrum; the lower end of this ridge is supported by slight ridges running toward the anterior and posterior faces of the centrum. These last ridges assume considerable importance in the more posterior vertebræ. The transverse process is present on the vertebræ, but broken from position and displaced somewhat to the rear. It has been figured in outline in its proper position, so that the nature of the posterior portion of the vertebra may be seen, but the dimensions and form are correct as figured. The process starting from the base of the spine decurved rapidly, and its distal face reached to the lower edge of the centrum. The notochordal portion of the centrum is confined to the upper half, and the lower is occupied by a narrow and prominent keel. The posterior face is somewhat lower than

the anterior, but this is not so pronounced as in the axis. The lower half of the anterior face is a flat surface, to which is still attached the intercentrum. This is crescentic in shape and rather broad on the lower face. On either side there are two prominent processes for the capitula of the ribs. Without the intercentrum the profile of the anterior face would be very similar to that of the axis.

MEASUREMENTS OF THE THIRD CERVICAL.

Length along bottom line of the centrum	0.038 m
Width posterior zygapophyses (somewhat crushed)	0.033
Horizontal diameter of posterior face of centrum	0.028
Vertical diameter same	0.028
Horizontal diameter anterior face	0.024

The *fourth cervical* is less well preserved than the third or fifth, and presents no great difference from the third. The transverse process is very wide, the width being due to a very thin extension of the anterior edge; this character persists through the anterior dorsal vertebræ. The ridges supporting the transverse process upon the centrum become very prominent running to the anterior and posterior edges of the centrum; these, with the prominent keel on the lower line of the centrum, form three very prominent ridges on the centrum about equally distant from each other. As in the third, the base of the spine is pinched by the deep fossæ on each side of its base.

MEASUREMENTS OF THE FOURTH CERVICAL.

Length along the bottom line of the centrum	0.038 m
Width of posterior zygapophyses	0.032
Horizontal diameter of anterior face of centrum	0.024
Vertical diameter same (including face for intercentrum)	0.028

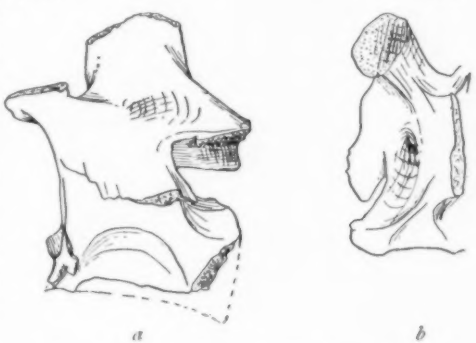
The *fifth cervical* (Fig. 13) differs from the preceding in the greater relative width of the pre- and postzygapophyses. This may be due in part to crushing of the preceding vertebræ, as the fifth is almost free from distortion, though not entirely so. The distal end of the transverse process is missing, but the whole process was inclined somewhat more to the rear than in the anterior cervicals. The ridge rising from the upper portion of the centrum and supporting the lower edge of the process is still

present but is shorter. The transverse process is rising from any contact with the centrum to a position on the base of the neural arch. The intercentrum is in position and is similar to the earlier ones. The keel on the lower edge is very thin and sharp and of considerable vertical extent. The posterior face of the centrum is no lower than the anterior. The base of the spine is still very thin, so that the spines probably were not greatly elevated.

MEASUREMENTS OF THE FIFTH CERVICAL.

Length along the bottom line of the centrum	0.032 m
Width of the posterior zygapophyses	0.043
Width anterior zygapophyses	0.039

The *sixth cervical* differs from the others in the relative shortness and the greater height of the centrum. The transverse process rises from the upper portion of the neural arch and is well above the neural canal and the centrum; the ridges on the centrum which supported the transverse process have lost connection with it and are present as rudiments which are evidently disappearing. The transverse process curves downward close to the centrum and trends very slightly to the rear; the lower end does not extend below the lower edge of the centrum. This is the first of the vertebræ posterior to the axis in which the intercentrum is not attached, but from the size of the articular space on the lower edge of the anterior face of the centrum it is evident that it was as large as the others and that its displacement is accidental. The articular faces of the zygapophyses are horizontal, and the keel on the lower portion of the centrum is very thin and prominent.



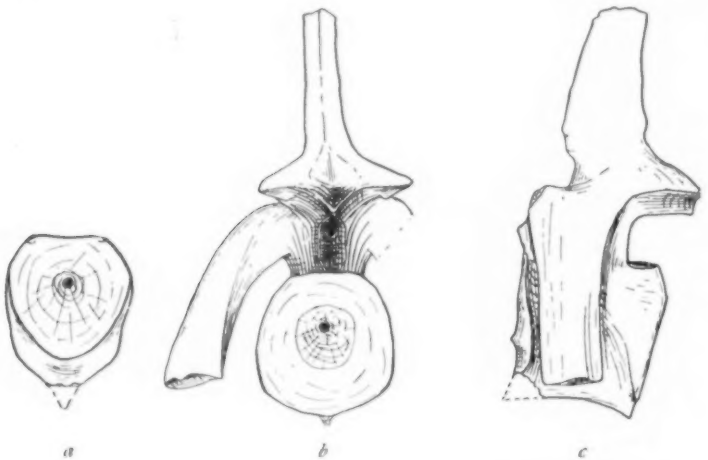
a *b*

FIG. 13.—Fifth cervical. *a*, from above; *b*, from the side. ⅔ natural size.

MEASUREMENTS OF THE SIXTH CERVICAL.

Length along bottom line of the centrum	0.029 m
Height of centrum from bottom to bottom of notch beneath post-zygapophyses	0.030
Width post-zygapophyses	0.040
Vertical and horizontal diameters of the posterior face of the centrum	0.033

The *seventh cervical* (Fig. 14) has the centrum relatively higher and shorter than the preceding, and the keel is much more



a *b* *c*

FIG. 14.—Seventh cervical.—*a*, anterior face of the centrum; *b*, posterior view of vertebra; *c*, side view. ⅔ natural size.

prominent. The edge of the keel forming the lower edge of the centrum is nearly straight. The intercentrum is absent, and the recurving of the lower portion of the edge of the anterior face in forming the face for the centrum shows very prominently the "twisted" appearance described by Cope. The transverse process rises from the neural arch quite above the neural canal and the centrum and decurves close to the side of the centrum. There is no trace of the ridges which supported the transverse process on the centrum in the anterior vertebræ; its distal end does not reach below the lower edge of the centrum. The trans-

verse process lacks something of the thin plate extending from its anterior edge which gives it the very broad appearance in the anterior cervicals and it is much stouter. In this vertebra for the first time the suture between the neural arch and the centrum is quite evident. On the upper edge of the anterior face of the centrum near the sides are small prominences seemingly articular in nature, but I can find no corresponding structure on the posterior faces of any of the vertebræ. The base of the neural spine is much stouter than in the preceding vertebra, and the spine was probably much more elevated.

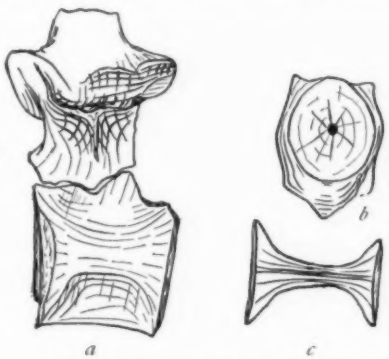


FIG. 15.—An anterior dorsal vertebra, the twelfth of the restoration. *a*, from the side; *b*, anterior face of the centrum; *c*, profile of the centrum from below. ⅗ natural size.

MEASUREMENTS OF THE SEVENTH CERVICAL.

Length along the bottom line of the centrum	0.029 m
Height of centrum as in the sixth	0.032
Horizontal and vertical diameters of the posterior face of the centrum	0.030
Width of the post-zygapophyses	0.033

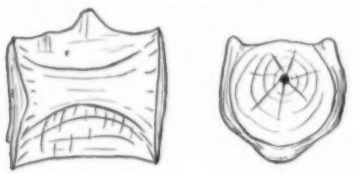
The next vertebra (Fig. 15) probably belongs farther back in the series. It is the twelfth of the restoration. The numbers used below are those of the restoration. This vertebra is typical of the dorsal series. It differs markedly from the vertebræ described as cervical, and not least in the fact that the neural arch and spine are separate from the centrum. The centrum is more high than long, and the keel is very prominent, forming at least half of the vertical extent of the centrum. The transverse process rises from the base of the neural spine and probably extended almost straight outward (this is true in *Dimetrodon*). The distal end of the transverse process is missing, but the base

even rises slightly after leaving the spine; at this point the process is very thin vertically and quite broad in an antero-posterior direction. The base of the transverse process rises from three ridges, two rising from beneath the anterior and posterior zygapophyses and a third vertical ridge on the side of the neural ral arch. The base of the spine is quite broad and strong. The spine was elevated. The pre- and postzygapophyses differ from the cervicals in that their antero-posterior diameter is relatively much less and the articular faces are no longer horizontal, but inclined outward as well as downward and inward as well as upward.

MEASUREMENTS OF THE TWELFTH VERTEBRA.

Length along the bottom line of the centrum	0.025m
Horizontal diameter of the posterior face of the centrum	0.028
Vertical diameter same	0.029
Antero-posterior extent of zygapophyses	0.040
Width of anterior zygapophyses	0.030

The *thirteenth* to the *sixteenth* vertebræ, inclusive, are very similar to the twelfth, and all belong in the dorsal series; the notable point is the gradual elongation of the centrum so the antero-posterior diameter becomes greater than the vertical. The neural arches are detached in all the dorsal vertebræ, but in the seventeenth the arch lies near the vertebra and shows that the character of the articular faces of the zygapophyses gradually change so that they are becoming more and more horizontal. The base of the neural spine is very broad, but there is a deep pit on either side. The anterior face of the centrum shows an articular face for an intercentrum. In Fig. 10 *c* is shown an intercentrum, probably from this region. It is noticeably smaller than the intercentra from the anterior portion of the column, and the faces for the capitula of the ribs are very small and are not supported on tubercles.



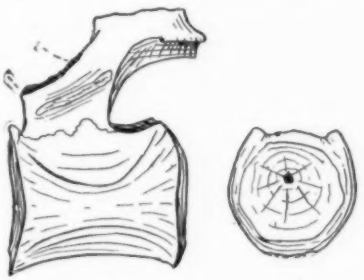
a *b*

FIG. 16.—A dorsal, the sixteenth of the restoration. *a*, from the side; *b*, anterior face of the centrum. ⅔ natural size.

MEASUREMENTS OF DORSAL VERTEBRÆ.

Length along bottom line of thirteenth	0.0275m
Length along bottom line of fourteenth	0.0245
Length along bottom line of fifteenth	0.032
Length along bottom line of sixteenth	0.031
Length along bottom line of seventeenth	0.0325
Length along bottom line of eighteenth	0.034

The *nineteenth* vertebra (Fig. 17) is characterized by the diminution of the keel. The lower edge of the centrum is rounded and the keel is indicated by a narrow line only. The anterior face of the centrum is rounded and quite similar to the posterior, there being but a small facet for the intercentrum. The zygapophyses are narrow and nearly horizontal, and the transverse process stood out at nearly right angles to the body of the centrum.



a *b*

FIG. 17.—A posterior dorsal, the nineteenth of the restoration. *a*, from the side; *b*, anterior face of the centrum. ⅔ natural size.

MEASUREMENTS OF THE NINETEENTH VERTEBRÆ.

Length along bottom line of the centrum	0.035m
Horizontal diameter of face of centrum	0.029
Vertical diameter of face of centrum	0.028
Vertical height of centrum to base of notch beneath post-zygapophyses	0.029

The *twentieth* to the *twenty-fourth* vertebræ, inclusive, are quite similar to the nineteenth, but show a gradual decrease in length, as shown by the measurements below:

MEASUREMENTS.

Length along bottom line of twentieth	0.036m
Length along bottom line of twenty-first	0.037
Length along bottom line of twenty-second	0.033
Length along bottom line of twenty-third	0.030

The edge of the anterior face of the centrum of the twenty-fourth vertebra is expanded into a slight face for the capitulum

of the rib; it is probable that the main portion of the capitulum was attached to the intercentrum, but we have here the first step in the formation of the type of articulation which is present in all posterior vertebræ. In other respects the vertebra resembles those immediately preceding it; the neural arch is attached to the centrum, but the sutural connection is very distinct. Attached to the spine of this vertebra is one of the intercentra such as is found in the posterior portion of the column. It is broadly crescentic, with but slight curvature, and is of considerable antero-posterior extent on the mid-line. The bone is very thin, and there are no faces for the capitulum of the rib; it is probable that the intercentrum is displaced and belongs farther back in the series. One thing seems very certain: the width of these intercentra is too great to permit their having occupied a position between the vertebræ in the anterior portion of the column, and there are no articular faces for them on the lower portion of the anterior face of the centrum. They must have rather underlain the point of union of the two vertebræ.

MEASUREMENTS OF THE TWENTY-FOURTH VERTEBRA.

Length along bottom line of centrum	0.0285m
Length intercentrum attached to spine	0.032
Width of the intercentrum antero-posterior	0.009

Beginning with the twenty-fifth, the series is complete and in position to the second caudal, so that it is certainly the seventh presacral.

The *twenty-fifth*, seventh presacral vertebra (Fig. 18), has the articular face for the capitular portion of the rib well developed, and the posterior edge of the face is supported by a strong protuberance from the side of the centrum.

Length along the bottom line of the centrum	0.027m

In the *twenty-sixth*, sixth presacral (Fig. 18), the base of the rib is still attached to the vertebra and shows clearly the change in the manner of articulation. The tuberculum is attached to a very short transverse process extending from the side of the neural arch and the capitulum to the articular face formed on the edge of the anterior face of the centrum. The articular face is quite large and stands out prominently from the

side of the centrum. The vertebræ are rapidly shortening again and the articular faces becoming relatively larger.

Length along the bottom line of the centrum - - - - 0.026^{m}

In the *twenty-seventh*, fifth presacral (Fig. 18), the rib seems to have completely lost its connection with the intercentrum. The tuberculum is attached to the downwardly inclined face of a very short transverse process and the capitulum to the edge of the centrum. The capitulum is gradually shortening. The neural spine is rather thin, but has considerable antero-posterior extent. The anterior and posterior zygapoyhyses are nearly horizontal, but the articular faces are somewhat curved.

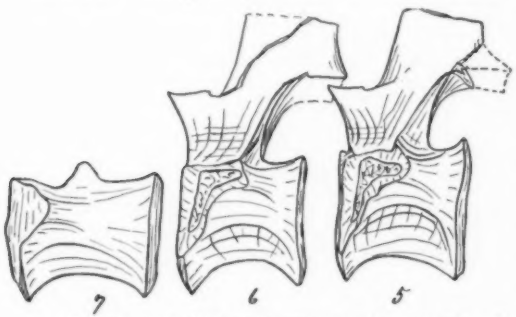


FIG. 18.—The fifth, sixth, and seventh presacrals. ⅔ natural size.

Length of the bottom line of the centrum - - - - - 0.023^{m}

The remaining presacrals show a considerable similarity. The *twenty-eighth*, fourth presacral (Fig. 19), has the broken base of the rib still attached and show that both tuberculum and capitulum are still present.

In the *twenty-ninth*, third presacral (Fig. 19), the capitulum is much reduced and the rib stands out almost straight from the upper portion of the centrum.

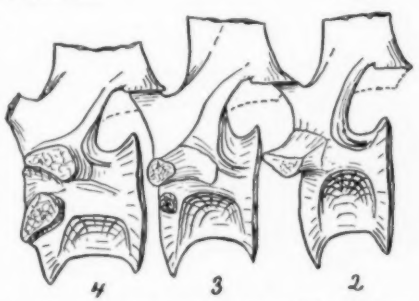


FIG. 19.—The second, third, and fourth presacrals. ⅔ natural size.

In the *thirtieth*, second presacral (Fig. 19), there is no trace of a capitulum, and the rib is a short stubby process.

The *thirty-first*, first presacral (Fig. 20), resembles the preceding in the arrangement of the rib.

As before mentioned the vertebræ are rapidly growing shorter and the last presacral is remarkably shortened. The length of the vertebræ is shown by the measurements given below.

Length along bottom line of the centrum of the twenty-eighth	0.022 m
Length along bottom line of the centrum of the twenty-ninth	0.019
Length along bottom line of the centrum of the thirtieth	0.016
Length along bottom line of the centrum of the thirty-first	0.013
Vertical diameter of the thirty-first	0.039
Horizontal diameter of the thirty-first	0.039

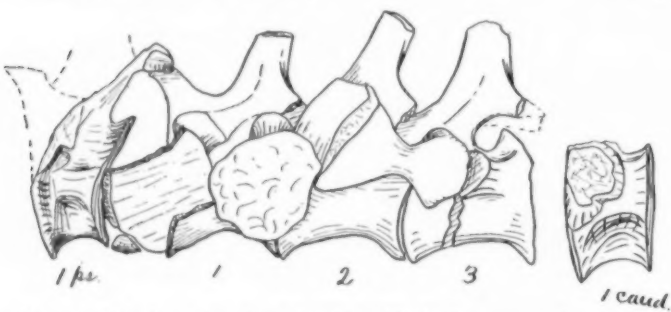


FIG. 20.—Sacral vertebræ from the side with the last presacral and the first caudal. ⅔ natural size.

In the specimen as preserved there is quite a space between the first sacral and the last lumbar, and in this space is a rather large intercentrum. It is quite broad antero-posteriorly and only slightly curved. The lower surface is quite rough, but this may in part be due to accidents of preparation. There is no possibility that there was a space between the vertebræ equal to the width of the intercentrum, so that it must have underlain the line of juncture.

Length of the intercentrum	0.032 m
Width of intercentrum antero-posteriorly	0.014

There are three *sacrals* (Figs. 20 and 21), which differ very markedly from the last presacral and the first lumbar in that they are of considerable relative length. The ribs are attached to the transverse processes and sides of the centrum; as in the

lumbars, and are very short, but the distal ends are greatly expanded for attachment to the ilium. The rib of the first sacral extends out almost straight from the sides of the vertebra, but in the second and third the ribs are strongly inclined forward; this is in part due to crushing, but is largely natural, as the articular faces for the proximal ends of the ribs, especially on the third sacral, are inclined forward quite sharply. The sacral vertebræ meet quite closely on the median line below, and there were no intercentra present, but there was no co-ossification. The spines are quite thin, noticeably more so than in the lumbars and first caudals, but of considerable antero-posterior extent; they were possibly not so elevated as the adjacent spines.

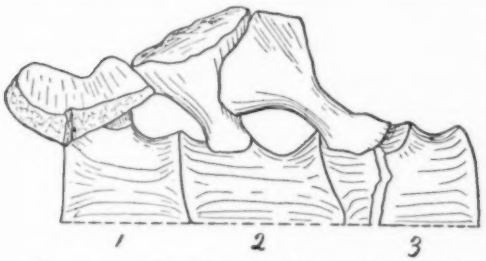


FIG. 21.—Sacral vertebræ from below. ⅔ natural size.

The *first sacral* is somewhat shorter than the others, and the bottom line of all is somewhat concave and is devoid of a keel.

Length along bottom line centrum of first sacral - - -	0.027 m
Length along bottom line centrum of second sacral - -	0.0325
Length along bottom line centrum of third sacral - - -	0.030

The *first caudal* is again short, 0.020 m. Along the bottom line of the centrum it is rather imperfect.

The *second caudal* (Fig. 22), is well preserved. The rib is short and rises much as in the lumbar vertebræ, from the neural arch and from a prominent process on the side of the centrum. The capitular portion extends well down the side of the anterior face. The process on the centrum

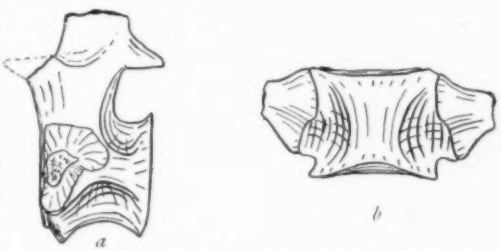


FIG. 22.—The second caudal vertebra. *a*, from the side; *b*, from below.

supporting the capitulum stands out as a rather prominent ridge separated from the obtuse keel of the lower line of the centrum by a deep pit; the whole effect is to give the vertebræ a triangular appearance in section. There are broad intercentra attached to the caudals, but not in position; there is no trace of chevron bones. The lower edges of the anterior faces of the caudals are reflected, making a face for the intercentrum, but those which are found on the vertebræ are too large to have been located between the vertebræ. The whole series of caudals decreases rapidly in size, indicating a short tail.

Length on bottom line of second caudal	0.0205 m
Length on bottom line of third caudal	0.018
Length on bottom line of fourth caudal	0.015

The accompanying restoration is largely from the specimen described above, but some parts have been taken from other specimens, and the ribs have been supplied *in toto* by comparison with the living *Spenodon*. The spines of the vertebræ are largely absent and have been supplied from a specimen of *Dimetrodon* in which the length of the limb bones was almost exactly the same as in the present specimen. The posterior foot has been drawn with Cope's figure of the posterior foot of *Clepsydrops* as a model. The notable weakness of the base of the spines of the sacral vertebræ has suggested that they were in all probability shorter than the others. Four vertebræ have been supplied in the anterior dorsal region, as there is an evident hiatus in the series at that point. The total number of presacral vertebræ is represented as thirty-one, and this cannot be very far from the correct number; this determination is made from the vertebræ of the present specimen and from the figure of the vertebral column of *Dimetrodon* published by Cope.[1] As explained above, this figure probably does not represent the complete column.

The body is drawn somewhat elevated from the ground. At first it seemed probable that the belly was dragged on the ground, but an attempt to place the bones of the fore limb in such a position showed that the relation of the femur to the cotyloid cavity and the head of the radius to the articular

[1] *Proc. Am. Phil. Soc.*, August, 1880, Figs. 3 and 3*a*, Pl. VI.

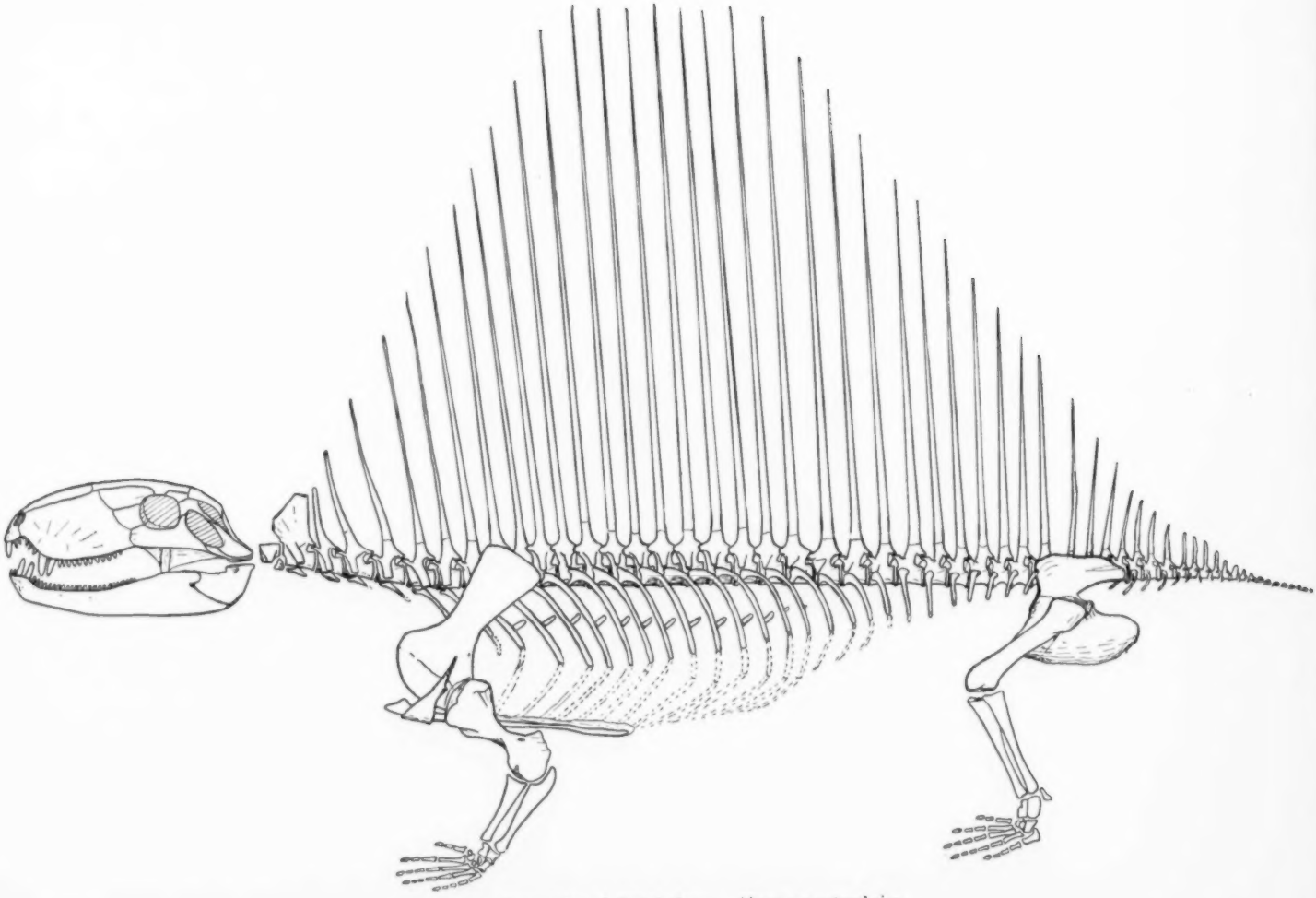


FIG. 23.—Restoration of *Embolophorus*. About 2·9 natural size.

process on the lower end of the humerus would not permit this. The tail would naturally seem to have been pretty long, if for no other reason, than to preserve the symmetry of the animal; but the condition of the caudal vertebræ seems to negative such a proposition. The vertebræ of all long-tailed forms gradually decrease in size and the middle and posterior ones assume the form of simple cylinders. In this specimen the vertebræ decrease rapidly in size and the ones which are only half as large as the first and second are as perfectly formed and as specialized as any in the series.

1. BAUR AND CASE. "The History of the Pelycosauria, with a Description of the Genus *Dimetrodon*." *Trans. Am. Phil. Soc.*, N. S., Vol. XX (1899).

2. E. D. COPE. "Systematic Catalogue of the Species of Vertebrates Found in the Beds of Permian Epoch in North America, with Notes and Descriptions." *Ibid.*, Vol. XVI (1886).

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Milwaukee, Wis.

THE CINCINNATI GROUP IN WESTERN TENNESSEE, BETWEEN THE TENNESSEE RIVER AND THE CENTRAL BASIN.

A. The subdivisions of the Cincinnati group in Ohio.
B. The Cincinnati group in the Tennessee river valley.
   1. The Saltillo limestone.
   2. The Warren limestone.
   3. The Richmond limestone.
   4. The Mannie shale.
C. The Cincinnati group between the Tennessee river valley and the Central Basin.
   5. The Leipers creek limestone.
   6. The Swan creek limestone.
D. Conclusions.

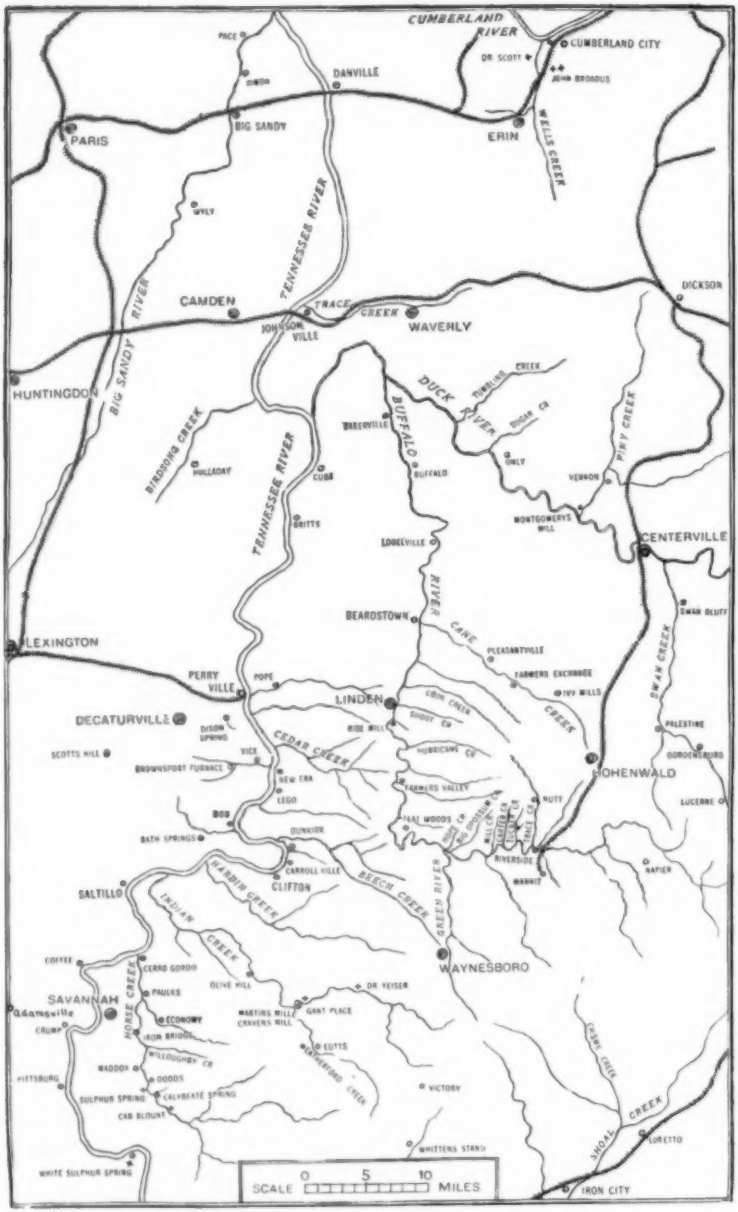
A. THE SUBDIVISIONS OF THE CINCINNATI GROUP IN OHIO.

In 1865 Meek and Worthen[1] proposed the name "Cincinnati group" for that part of the Ordovician which is exposed in Ohio.

In 1873 Professor Orton[2] divided the Ordovician of Ohio into three divisions. The middle division included all rocks exposed within the boundaries of the city of Cincinnati; its inferior limit was at low water of the Ohio river, its upper boundary was formed by the highest stratum found in the Cincinnati hills. This middle division was called by Professor Orton the *Cincinnati beds proper*. All rocks above the highest stratum exposed in the Cincinnati hills and below the lowermost beds of Silurian age (the Upper Silurian of the Ohio Survey and of most authors) were included in the upper division. The strata that form the summit of the Cincinnati hills are found also in the immediate vicinity of Lebanon. The base of the upper division is also well exposed here, and its fauna has been carefully studied by local collectors. Therefore the name *Lebanon beds* was given to the upper division, although the nearest outcrops of the top of the Lebanon beds are about seven miles north of Lebanon, and

[1] *Philadelphia Acad. Nat. Sci., Proc.*, Vol. XVII, p. 155.

[2] *Ohio Geol. Surv.*, Vol. I, pp. 370–73.


CUMBERLAND RIVER
CUMBERLAND CITY
DR. SCOTT
JOHN BRODUS
DANVILLE
PACE
DIXON
PARIS
BIG SANDY
ERIN
WELLS CREEK
DICKSON
CAMDEN
TENNESSEE RIVER
TRACE CREEK
JOHNSONVILLE
WAVERLY
BIG SANDY RIVER
HUNTINGDON
BIRDSONG CREEK
HOLLADAY
CUBA
GRITTS
BUFFALO
BARRENVILLE
DUCK RIVER
TUMBLING CREEK
DIGGS CR
PINEY CREEK
VERNON
MONTGOMERYS MILL
CENTERVILLE
LOBELVILLE
BEARDSTOWN
CANE RIVER
SWAN BLUFF
SWAN CREEK
PALESTINE
GORDONSBURG
LEXINGTON
PERRYVILLE
POPE
PLEASANTVILLE
FARMERS EXCHANGE
IVY MILLS
LINDEN
DECATURVILLE
DIXON SPRING
SCOTTS HILL
BROWNSPORT FURNACE
CEDAR CREEK
NEW ERA
LEGO
BOB
BATH SPRINGS
DUNKIN
CARROLL VILLE
CLIFTON
HOHENWALD
LUCERNE
NUTT
FARMERS VALLEY
HURRICANE CR
SALTILLO
HARDIN CREEK
INDIAN CREEK
BEECH CREEK
GREEN RIVER
RIVERSIDE
NAPIER
WAYNESBORO
COFFEE
CERRO GORDO
OLIVE HILL
DR YEISER
SAVANNAH
Adamsville
CRUMP
PAULKS
ECONOMY
IRON BRIDGE
MARTINS MILL
CRAVENS MILL
GANT PLACE
HORSE CREEK
WILLOUGHBY CR
MADDOX
DODDS
PITTSBURG
SULPHUR SPRING
CALYBEATE SPRING
CAB BLOUNT
WHITE SULPHUR SPRING
VICTORY
WHITTENS STAND
SHOAL CREEK
LORETTO
IRON CITY
SCALE 0 5 10 MILES

the intervening section is poorly exposed. Those Ordovician rocks of Ohio which stratigraphically belong below those exposed at low-water mark in Cincinnati were included in the lower division. The best and clearest section of these rocks is seen near Point Pleasant, about twenty-five miles above Cincinnati, on the Ohio river. Although the upper boundary of the lower division cannot be readily determined with exactness at this locality, the rocks included within this division were called the *Point Pleasant beds*.

At present the term *Cincinnati group* no longer includes all of the Ordovician rocks exposed in Ohio. Since the Point Pleasant beds and the lower fifty feet of rock at Cincinnati have been identified as equivalent to the upper part of the Trenton, the term *Cincinnati group* has been restricted so as to include only the remainder of the *Cincinnati beds proper* and the *Lebanon beds* of Orton.

In 1897 Winchell and Ulrich[1] divided the *Cincinnati beds proper* of Orton into two divisions, identifying the lower with the *Utica*[2] of New York, and the upper with the *Lorraine*. For the term *Lebanon beds* they substituted the term *Richmond group*, since the name *Lebanon* had been used by Professor Safford for a formation included in the Trenton group of Tennessee, before Professor Orton applied it to his upper division of the Cincinnati group. No sections are described, but at Cincinnati the Utica is said to be over 250 feet thick, and the Lorraine about 200 feet. The line between the Utica and Lorraine is sufficiently well established, to anyone acquainted with the Cincinnati section, by the statement that at the base of the Lorraine there are some arenaceous layers that on weathering frequently preserve the fossils as casts, and that above these there are numerous layers of crystalline limestone, three to ten inches in thickness, separated by relatively thin bands of shale. The line of division between the Utica and Lorraine is evidently the same as that between beds XI and XII of Ulrich.[3]

[1] *Minnesota Geol. and Nat. Hist. Surv., Final Rept.*, Vol. III, Part II, p. ci.

[2] ULRICH, "Correlation of Lower Silurian Horizons," *Am. Geol.*, Vol. I (1888), p. 315.

[3] *Ibid.*, Vol. II, p. 41

In 1896 Harper and Bassler[1] adopted the division of the Cincinnati group made by Winchell and Ulrich in the preceding paper, written at an earlier date but still unpublished. The Lorraine is said to be terminated above by a widely distributed bed containing rolled fragments and entire specimens of the large form of *Platystrophia lynx* in great abundance. The Richmond group comprises the overlying part of the Cincinnati group and is, therefore, the exact equivalent of the Lebanon beds of Orton.

In 1900 Nickles and Bassler[2] adopted the division of the Cincinnati group into the Utica, Lorraine, and Richmond. Their lists of fossil bryozoa established still more definitely the line between the Utica and the Lorraine, as identified by Ulrich. The line between the Lorraine and the Richmond is apparently still the same as that between the Cincinnati beds proper and the Lebanon beds of Professor Orton.

In 1902 J. M. Nickles[3] referred the lower 80 feet of the Lebanon beds of Orton to the Lorraine, thus increasing the section to be identified as Lorraine and diminishing the section to be included in the Richmond. The strata including the thin *Dinorthis retrorsa* bed are for the first time definitely[4] excluded from the Richmond. The base of the Richmond was placed just beneath the lowest beds containing *Strophomena rugosa* (the *Strophomena planumbona* of the Ohio Survey), *Rhynchotrema capax*, *Dalmanella jugosa* and *Streptelasma rusticum* (the *Stroptelasma corniculum* of the Ohio Survey. The Lorraine of Ohio, as extended by Nickles, was then subdivided into six sets of beds, called, in descending order: the Warren beds, 80 feet thick; Mount Auburn beds, 20 feet; Corryville beds, 60 feet; Bellevue beds, 20 feet; Fairmount beds, 80 feet; and the Mount Hope beds, 50 feet. The Warren beds include those formerly referred to the Lebanon beds by Orton, but transferred to the Lorraine by Nickles. The Mount Auburn beds include the highest strata

[1] *Catalogue of Fossils in Vicinity of Cincinnati, O.* Private publication.

[2] "Synopsis of American Fossil Bryozoa," *Bulletin U. S. Geol. Surv.*, No. 173.

[3] "The Geology of Cincinnati," *Jour. Cincinnati Soc. Nat. Hist.*, Vol. XX, No. 2.

[4] ULRICH, "Correlation of Lower Silurian Horizons," *Am. Geol.*, Vol. II (1888), p. 41.

exposed in the Cincinnati hills. They are also known as the *Platystrophia lynx* beds, on account of the great abundance of a characteristic variety of this fossil which attains a large size and has a short hinge line. Both the Warren and the Mount Auburn beds are well exposed north of Lebanon, O. The Fairmount beds are well exposed immediately west of the river at Hamilton.

Mr. J. M. Nickles determined the thickness of the Utica to be 260 feet at Cincinnati, and the thickness of the Lorraine at the same locality as 310 feet. The thickness of the Richmond was stated to be between 200 and 300 feet, the locality not being mentioned. At the more northern exposures in Indiana its thickness appears to be 240 feet, according to measurements by the present writer.

Judging from exposures in Nelson and Washington counties in central Kentucky, and from outcrops along the Cumberland river in southern Kentucky, the Lorraine becomes thinner southward. The rate of thinning, however, is much less than that of the Richmond in the same distance. In Marion county in central Kentucky the Richmond does not exceed 35 feet. Along Fishing creek,[1] a tributary of the Cumberland river, the Richmond is at least 27 feet thick.

B. THE CINCINNATI GROUP IN THE TENNESSEE RIVER VALLEY.

The Utica, Lorraine, and Richmond groups may be identified also in Southwestern Tennessee, along the Tennessee river and some of its tributaries.

1. *The Saltillo Limestone.*—The Utica consists of fine-grained, gray or bluish-gray limestone layers, from 2 to 5 inches thick, interbedded with equal thicknesses of shaly clay. At Clifton, on the Tennessee river, attempts were made before the war to burn it into a cement; it is, therefore, referred to by Professor Safford[2] as the hydraulic limestone. He estimates its thickness at Clifton as 70 feet down to low water, its base not being exposed at any point in the Tennessee river valley in western Tennessee.

[1] "The Cincinnati Anticline in Southern Kentucky," *Am. Geol.*, December, 1902.

[2] *Geology of Tennessee*, 1869.

The limestone is exposed also twelve miles eastward, three and one-half miles northwest of Waynesboro, near the home of W. D. Helton on Beech creek; here it is overlaid by the limestone forming the base of the Richmond group. It occurs off and on down Beech creek as far as its junction with Little Beech creek, and is exposed also along the road from Waynesboro to Clifton, a short distance west of the home of W. D. McAnally, near the crossing of Eagle creek, three miles east of Clifton.

The most southern exposure occurs about twenty miles southwest of Clifton, at the mill variously known as the Maddox, Welch, or Old Graham mill, located on Horse creek. Here only the upper fifteen feet of the limestone is exposed, overlaid by a few inches of clayey material belonging to the Richmond. The Utica is the only Ordovician rock exposed along Willoughby creek from its mouth at Lick Ford, for several miles up stream. It occurs along the lower parts of Indian and Hardin creeks. The most western outcrop is located on Miles creek, one mile south of Saltillo, at the site of an old mill, a quarter of a mile above the mouth of the creek.

The typical section occurs at Clifton, on the Tennessee river; however, since the name Clifton has already been applied by Professor Safford to the Silurian of Tennessee, the name *Saltillo* has been chosen.

The Saltillo limestone contains comparatively few species of fossils, and most of these are not abundant. The most widely distributed species is a variety of *Dalmanella emacerata*,[1] 20[mm] in width, which is abundant at Clifton and on Beech creek, northwest of Waynesboro. There is also a smaller variety of Dalmanella at Clifton, with coarser plications, identified as *Dalmanella multisecta*.[2]

In addition to the Dalmanellas named, the following fossils have been found in the Saltillo limestone at Clifton. *Zygospira modesta* is very abundant in several layers near the top of the limestone. A globular sponge with acicular spicules is very abundant in one of the lower layers; it is probably a species of

[1] *Pal. New York*, Vol. VIII, Plate V *c*, Fig. 2.

[2] *Pal. Olivo*, Vol. I, Plate VIII, Fig. 1, *a*, *b*, *c*.

Hindia related to *Hindia gregaria*. In some layers a brachiopod, identified as *Leptobolus insignis*, is abundant and well preserved. This fossil occurs at Cincinnati only in the lower third of the Utica, and it is the presence of *Leptobolus insignis* and *Delmanella emacerata* in the Saltillo limestone which has led to its identification as equivalent to the Utica.

In the Wells creek basin, along the railroad southwest of Cumberland City, in northwestern Tennessee, a series of limestones interbedded with shaly clays occur which lithologically resemble the Saltillo limestone of southern Tennessee. A slight resemblance is shown also by that part of the Cape Girardeau limestone which is interbedded with shaly clay. The top of the Cape Girardeau limestone belongs to the Silurian. The fossils so far collected from the Ordovician part of the Cape Girardeau limestone indicate merely an age corresponding to the lower part of the Cincinnati group, but whether they are Utica or Lorraine cannot be determined with the evidence at hand. The Richmond group appears to occur in Jefferson, Warren, and Pike counties, in Missouri, judging from the presence of *Dinorthis subquadrata*, *Platystrophia acutilirata*, and *Strophomena planumbona*.[1] While Richmond group fossils are listed from localities farther south, along the Mississippi, nearer to Cape Girardeau, they are listed together with other fossils which are certainly not of Richmond age, suggesting a possibility of incorrect determination.

2. *The Warren limestone*.—If the occurrence of *Leptobolus insignis* is sufficient to refer the Saltillo limestone to the Utica, then the Lorraine has a very limited geographical extent in the Tennessee river valley. At Clifton, above the landing, the northeastern end of the outcrop of Lorraine has a thickness of three feet four inches. At the old cement mill at the southwestern end of town, its thickness is only a few inches. The Lorraine has not yet been detected elsewhere. This is rather surprising, since Mr. J. M. Nickles states that at Columbia, sixty miles east of Clifton, Mount Parnassus is a noted locality for Lorraine fos-

[1] *Missouri Geol. Surv.*, Vol. V, 1894; also SHUMARD, *Reports* for 1855–71, and SWALLOW, *Reports* 1 and 2, 1855.

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sils,[1] and the section there is considerable.[2] The Lorraine at Clifton consists of gray or bluish-gray, coarse-grained limestone which may be readily distinguished from the Richmond limestone immediately above by the presence of considerable chert. It is very fossiliferous, but the fossils must be broken out of the rock and do not form good cabinet specimens.

The most common and at the same time most characteristic fossil is *Dinorthis retrorsa*. In Ohio and Indiana this fossil has a very limited vertical range, being confined to a bed, rarely exceeding one or two feet in thickness, near the top of the Lorraine. This bed is included in the subdivision to which Mr. Nickles gave the name "Warren bed." The Lorraine bed at Clifton, here described, is therefore identified as the Warren limestone.

Another rather abundant species is a form of *Rhynchotrema dentatum* which differs from that found in the Richmond in the possession of three distinct plications and one indistinct plication on either side of the dorsal fold instead of four distinct and one or two indistinct plications, as in the Richmond group. In consequence, the plications appear more angular. This form occurs also at the top of the Lorraine half a mile southwest of Howards mill, in Montgomery county, Ky.

Leptæna rhomboidalis is fairly common. This species occurs associated with *Dinorthis retrorsa* also at the base of the Morris Hill section, in the hollow directly west of the mouth of Cæsar's creek, in Warren county, O.

A Dalmanella, belonging to the group of *D. testudinaria*, is very common. The dorsal valve is flat and has a distinct mesial depression, extending from the beak to the anterior margin. The plications bifurcate two or three times. It resembles most the form identified in Indiana and Ohio as *Dalmanella jugosa*[3], and differs chiefly in having a flat dorsal valve and coarser plications. The typical forms of *Dalmanella jugosa*, on the contrary, have a moderately convex dorsal valve. Both forms are common at the

[1] *The Geology of Cincinnati*, p. 74.

[2] SAFFORD, *The Geology of Tennessee*, p. 265.

[3] HARPER AND BASSLER, 1896, *Catalogue of Fossils of Cincinnati*, p. 16; NICKLES, 1902, *Geology of Cincinnati*, p. 92.

base of the Richmond in Indiana, Ohio, and northeastern Kentucky, and at some of the more northern localities they occur also at the top of the Lorraine, but usually in much smaller numbers. In fact, the base of the Richmond in Indiana and Ohio and northeastern Kentucky is usually indicated by the presence of several thick layers of limestone, often wave-marked, and a first appearance or sudden increase of *Dalmanella jugosa* and of its related form.

A large form of *Cyclonema bilix*, having a vertical height of fully one inch, is not rare. It appears most closely related to the typical forms as illustrated by Ulrich.[1]

Helcionopsis striata is represented by a single specimen, showing the characteristic markings on the surface. The specimen is, however, only 14^{mm} long. The type specimen[2] was found in "the upper beds of the Cincinnati formation, Marion county, Ky." Since the thickness of the Richmond formation in this county does not exceed 35 feet, it is very probable that the type specimen also came from the upper part of the Lorraine.

Columnaria stellata (*Columnaria alveolata* as identified by Nicholson)[3] is represented by a single specimen, showing alternately larger and smaller septa, the larger extending nearly or quite to the center of the visceral chamber.

3. *Richmond limestone.*—Immediately above the Warren bed, at Clifton, there are nineteen feet of Richmond limestone. The lower and middle part is coarse-grained, often cross-bedded, has a lighter color, and contains very few fossils. The upper part is more clayey and finer grained, forming a transition to the Richmond shaly clays immediately above. The top of the coarse-grained limestone and the clayey limestone above contains a greater number of fossils, but these are usually imbedded in the rock and cannot be secured without a considerable expenditure of time.

The identification of this limestone as Richmond is based upon the presence of a single specimen of *Rhynchotrema capax*

[1] *Minnesota Geol. Surv.*, Vol. III, Part II, Pl. LXXVII, Fig. 35.

[2] *Ibid.*, p. 827.

[3] *Pal. Province of Ontario*, 1875; also, *Paleozoic Tabulate Corals*, 1879.

at the base of the limestone near the old abandoned cement mill at the southwestern end of the town, and of a specimen of *Strophomena planodorsata*.

The form of *Rhynchotrema capax* found at the base of this limestone is much more abundant at the top of the limestone and in the overlying Richmond clay; it is most numerous near the top of the clay, one specimen being found even included in the Clinton rock, half an inch above its base. This form differs from the Rhynchotrema capax of the Richmond of Ohio, Indiana, and Kentucky, chiefly in size. It is smaller; the largest and most obese specimen so far found does not exceed 20^{mm} in thickness and 16^{mm} in width. It is also more narrow, and while the typical specimens from the Richmond of Indiana and Ohio have five distinct plications on either side of the fold of the dorsal valve, the Tennessee specimens here described have seven, and occasionally even eight, plications. The internal markings are the same. It may be called *Rhynchotrema capax manniensis*.

The dorsal valve of *Strophomena planodorsata*[1] is slightly concave over an area exceeding half the length of the shell, and has a flat appearance over an area equaling two-thirds of its length. The striæ are even finer than those figured by Winchell and Schuchert. One specimen occurred nine and one-half feet above the base of the Richmond limestone and others were found near the top. *Rafinesquina alternata*, *Plectambonites sericeus*, and *Hebertella sinuata* also occur.

The most interesting fossil is a species of *Lingulops* belonging to the subgenus typified by *Lingulops granti*,[2] a Silurian species from Hamilton, Ontario. It agrees in having the muscular area of the pedicle valve developed into a well-defined platform the anterior edge of which is not prolonged into a septum. Its length is 6^{mm}. The median impression between the central muscular scars is relatively more narrow; the platform does not extend as far toward the beak; the position of the pedicle may be recognized. The name *Lingulops cliftonensis* is suggested.

[1] *Minnesota Geol. Surv.*, Vol. III, Part I, p. 393.

[2] *Pal. New York*, Vol. VIII, Part I, Pl. IV K, Fig. 15.

Richmond limestone is also exposed a short distance up stream from the home of W. D. Helton, on Beech creek, northwest of Waynesboro. It is seven feet thick, is rather coarse-grained, varies in color from light brown to bluish-gray, and is fossiliferous.

Among these fossils are the forms identified as *Strophomena planodorsata; Rafinesquina alternata;* a large *Cyclonema bilix* similar in form to that found in the Warren bed at Clifton, but having a vertical height of 36^{mm}; and a form of Dalmanella with a moderately convex dorsal valve, evidently related to *Delmanella iugosa* as found in the Richmond of Ohio and Indiana.

4. *The Mannie shale, or shaly clay.*— Immediately above the Richmond limestone, at Clifton, there is 15½ feet of brownish and bluish shaly Richmond clay. It contains *Rafinesquina alternata, Plectambonites sericeus*, and *Rhynchotrema capax manniensis.* A single specimen of *Dinorthis subquadrata* was found imbedded in the Clinton, one inch above its base. The characteristic muscular area is exposed. The plications are somewhat finer and more numerous than in the Richmond of Ohio, Indiana, and Kentucky. The presence of *Rhynchotrema capax manniensis* in the base of the Clinton has been noted already. They are simply Richmond specimens loosened from the clay beneath and mingled by the wash of Clinton seas with living Clinton forms.

Northwest of Waynesboro, on Beech creek, near the home of W. D. Helton, the 20 to 25 feet of section between the Richmond limestone and the Clinton, not exposed, probably consist of Richmond clay.

The upper part of the Richmond clay is seen beneath the Clinton just north of the west end of the railroad bridge across the Buffalo river northwest of Riverside, a mile and a half north of Mannie or Allens creek. Six feet is exposed; unfossiliferous.

About three-quarters of a mile west of Riverside, west of Mr. Howard's home on the road to Flat Woods, east of the mouth of Trace creek, the Richmond shaly clay is exposed on the north side of the road. The exposure is 33½ feet thick; the base of clay is not seen. The lower 11 feet of the section consists of fossiliferous weathered clayey rock; the fossils are found chiefly

in the upper half of this rock. Above this are 8 feet of weathered clayey limestone in which fossils are very few. This is overlaid by 14½ feet of clay, apparently unfossiliferous at this locality. The name "Mannie shale" is suggested for the shaly clay which forms the upper part of the Richmond in western Tennessee.

The most common fossil is *Rhynchotrema capax manniensis*. A form identified as *Dalmanella jugosa* is also abundant. A single pedicle valve of *Strophomena rugosa* (*Strophomena planumbona* of the Ohio Survey) was found, exposing the interior, also a single dorsal valve of the form identified as *Strophomena planodorsata*. *Platystrophia cypha* is not rare. The largest specimen is 37^{mm} wide, the postero-lateral angles equal about 65°, the fold of the brachial valve is occupied by four plications, and on each side of the fold there are about twelve lateral plications. In Ohio and Indiana this form extends from the upper part of the Lorraine to the top of the Richmond. *Platystrophia acutilirata* may be regarded as the most aberrant variation. One specimen of *Platystrophia crassa* was found, and one of *Plectambonites sericeus*. The most interesting specimen, however, is a single specimen of *Lingulasma*[1] preserving the characteristic ornamentation of the surface, and showing enough of the interior structure to suggest its generic relationship, but it is too poorly preserved to warrant a more specific description. It is about half as large as the species hitherto described.

North of Clifton, both the Richmond limestone and the Richmond clay may be traced for a considerable distance along the Tennessee river. Southward, the Richmond thins out rapidly. At the Maddox mill, on Horse creek, a few inches of clayey material intervenes between the top of the Saltillo limestone and the base of the Clinton. In this clay was found a specimen which is identical with *Helcionopsis striata* in form, but it does not preserve the surface striæ, being evidently an internal cast. Its length is 21 mm. There is also a single specimen of *Rhynchotrema capax manniensis*, and of *Leptaena rhomboidalis*. Possibly

[1] *Pal. New York*, Vol. VIII, Part I, Pl. II; also, *Minnesota Geol. Surv.*, Vol. III, Part I, Pl. XXX.

this clay represents residual material both from the Warren limestone and from the Richmond beds It is impossible to determine from the evidence at hand. There is no doubt, however, of the thinning out both of the Warren bed and of the two members of the Richmond group southwestward, on approaching the southern part of Hardin county.

C. THE CINCINNATI GROUP BETWEEN THE TENNESSEE RIVER VALLEY AND THE CENTRAL BASIN.

It should be noticed in this connection that the Clinton also thins out southwestward. At Newsom it is 30 feet thick. At Centreville 20 feet of Clinton is exposed and the base is not seen; it may therefore approach 30 feet in thickness. However, at Riverside, north of the railroad bridge, the thickness of the Clinton is only 5 feet 9 inches, and it consists of strongly cross-bedded limestone. At Dunkirk, about three miles below Clifton, its thickness is 3 feet 9 inches. At Clifton it does not exceed one foot. South of Clifton it has not been recognized. If it occurs at Maddox mill, it cannot be distinguished from the Osgood limestone at that point.

5. *The Leipers creek limestone.*—About thirty-two miles northeast of Riverside, along Leipers creek, Richmond limestone is well exposed. It occurs two and one-fourth miles south of Fly, near the top of the bluff north of the home of J. M. Gardner; also a quarter of a mile north of Fly, in the bed of the creek, and for some distance along the branch of Leipers creek which passes the homes of Carol Litton and Tom Fox, near the old *Oil Well*. The limestone varies from 6 to 9 feet in thickness, is coarse-grained, often crinoidal, and frequently has a salmon-brown color. It contains a species of Strophomena regarded by Mr. Charles Schuchert as closely related to *Strophomena Wisconsinensis*, as far as could be determined without seeing the interiors; also forms resembling *Strophomena rugosa*, and the form identified as *Strophomena planodorsata*. To this Richmond limestone the name *Leipers creek limestone*[1] has been given.

Overlying the limestone is a clay shale which corresponds

[1] "Silurian and Devonian Limestones of Tennessee and Kentucky," *Bull. Geol. Soc. Am.*, Vol. XII (1901).

stratigraphically with the *Mannie shale*. Above the limestone at the J. M. Gardner locality it contains *Rhynchotrema capax manniensis*. A quarter of a mile northeast of Fly, beyond the home of R. S. Elam, the bed is 6 feet thick, and contains about 1 foot of poor shaly limestone 1 foot above the base. In the shale and in the interbedded shaly limestone are found *Orthis proavita; Dinorthis subquadrata;* a form of *Hebertella insculpta* with finer striæ, and with a deeper median depression in the dorsal valve than is usual in Ohio specimens; a typical specimen of *Platystrophia acutilirata;* typical specimens of *Strophomena neglecta;* and specimens of Rafinesquina which belong to the group of *Rafinesquina minnesotensis inquassa*, showing distinctly the median septum and less distinctly the lateral septa characteristic of the dorsal valve. A very large form of *Hebertella occidentalis*, often 50^{mm} wide, occurs both at the Elam locality and in the 4 feet of clay which overlies the Leipers creek limestone north of the home of Tom Fox. At some localities the clay is absent.

The Leipers creek bed crops out again ten miles north of the Tom Fox locality, along the valley of the South Harpeth creek. It is still a coarse-grained limestone, usually crinoidal, but its color is bluish, with small brownish spots. Its thickness is also about the same, varying from 5 to 9 feet. It occurs in the creek bed south of Fernvale; one mile southeast of Fernvale on the road to Leipers Fork post-office, at the home of Mrs. Annie Inman; at the schoolhouse two miles north of Fernvale; north of the mouth of the branch entering South Harpeth creek a quarter of a mile south of the home of Jim Linton, Sr.; and apparently also back of the home of W. M. Forehand, half a mile west of Tank.

At the first two localities the limestone is directly overlaid by the Chattanooga black shale (Devonian). At the other localities it is overlaid by Richmond clayey shale, equivalent to the Mannie shale. The thickness of the Richmond shale does not exceed 10 feet at any locality visited.

At the Inman locality the limestone contains *Dinorthis subquadrata*, and a species of *Strophomena*. At the schoolhouse

north of Fernvale, the limestone contains *Orthis proavita*, *Dinorthis subquadrata*, *Hebertella insculpta*, and *Strophomena rugosa subtenta*. The clay shale immediately above the limestone appears to be unfossiliferous.

Richmond limestone is exposed three miles north of the Forehand locality, along the banks of the Harpeth river, at Newsom. It is a coarse-grained limestone, varying from bluish to light brown, and at least 10 feet thick. Its age is indicated by the presence of a single ventral valve of *Dinorthis subquadrata*, showing the muscular scar. The unexposed part of the section, between the Richmond limestone and the base of the Clinton, may be occupied by Richmond clay.

The most northern exposure of Richmond limestone, equivalent stratigraphically to the Leipers creek limestone, occurs at Baker, twenty-three miles northeast of Newsom. Here it is four feet thick, is a coarse-grained limestone, and contains *Strophomena Wisconsinensis*, or at least a form closely resembling this species in general appearance. No Richmond shale was noticed.

6. *Swan Creek Limestone.*—At Newsom the coarse-grained limestone is underlaid by clayey rock which contains numerous specimens of the form identified in Ohio and Indiana as *Dalmanella jugosa;* it there extends from the upper beds of the Lorraine through the lower part of the Richmond; the dorsal valve is slightly convex. Four typical specimens of *Rhynchotrema dentatum* were found. The presence of a single specimen of *Platystrophia lynx* with a short hinge line suggests the Lorraine age of this rock. The thickness of the clayey rock is not known, only a few feet being exposed above the level of the river.

Platystrophia lynx was also noted below the Leipers creek bed at the Inman locality, a mile southeast of Fernvale.

At the J. M. Gardner locality the Leipers creek limestone is underlaid by a considerable thickness of more or less cross-bedded limestone containing very few fossils, and this in turn is underlaid by clayey limestones in which fossils are numerous.

All along the Swan Creek valley, cross-bedded Ordovician limestone containing very few fossils is very well exposed. At the spring, a quarter of a mile south of Swan Bluff, it measures

about fifty-six feet, and is underlaid by the richly fossiliferous, more clayey layers, containing *Platystrophia lynx*. It also occurs up the valley along the railroad south of Centreville. To this cross-bedded, nearly unfossiliferous, Ordovician limestone the name "Swan creek limestone" is here given. Judging from the exposures at Swan Bluff and at the J. M. Gardner locality, it is of Lorraine age, probably below the *Dinorthis retrorsa* horizon.

At the quarry, a sixth of a mile up the hollow, east of the home of J. D. Dean, this cross-bedded limestone has disintegrated into a brownish mass which has been quarried as brown phosphate. The cross-bedded limestone which occurs at Clifton, and which has there been identified as Richmond, has also disintegrated into a brown phosphate rock immediately below the old cement mill at the southwestern end of the town. It appears, therefore, that waters sufficiently turbulent to produce cross-bedding were present during the deposition of both the upper Lorraine and of the lower part of the Richmond in western Tennessee. The Leipers creek bed is often cross-bedded, as well as coarse-grained. Between the cross-bedded Swan creek limestone and the coarse-grained Leipers creek limestone, a thin section of clayey rock, apparently of Lorraine age, intervenes in places. This is probably the position of the clayey rock at the base of the section at Newsom.

D. CONCLUSIONS.

According to the preceding observations, the Ordovician exposures in the valleys of the Tennessee river, the Buffalo river, Swan creek, Leipers creek, and South Harpeth creek suggest the following lithologic succession, in descending order:

Cincinnati Group.	Richmond	Mannie shale. Leipers creek limestone.
	Lorraine	Warren limestone; clay rock at Newsom. Swan creek limestone. Richly fossiliferous Lorraine limestone in the eastern part of the area studied, containing *Platystrophia lynx*.
	Utica	Saltillo limestone.

The Lorraine appears to become thinner west of the Cincinnati anticline, so as to be represented by thinner sections or so

as to be entirely absent along the Mississippi in Missouri and adjacent Illinois, in the Wells creek basin in northern Tennessee, and along the Tennessee river in southern Tennessee. The Richmond also appears to become thinner west of the northern half of the Cincinnati anticline. It becomes thinner also southward along the flanks of the anticline. In some parts of Tennessee it is entirely absent along the western flank of the anticline. West of the southern half of the anticline, in Tennessee, the thickness of the Richmond appears to vary irregularly. It has not been detected in the Wells creek basin. A thicker clay section than usual is seen west of Riverside. Both the limestone and clay are thicker at Clifton than at most points nearer the anticline. In the southern part of Hardin county, the Richmond thins out to a few inches. If the identification of the Saltillo limestone as lower Utica, and of the overlying limestone at Clifton as the Warren bed, is correct, a very considerable interval of erosion occurred during the middle of the Cincinnati age in western Tennessee.

AUG. F. FOERSTE.

THE HURRICANE FAULT IN SOUTHWESTERN UTAH.

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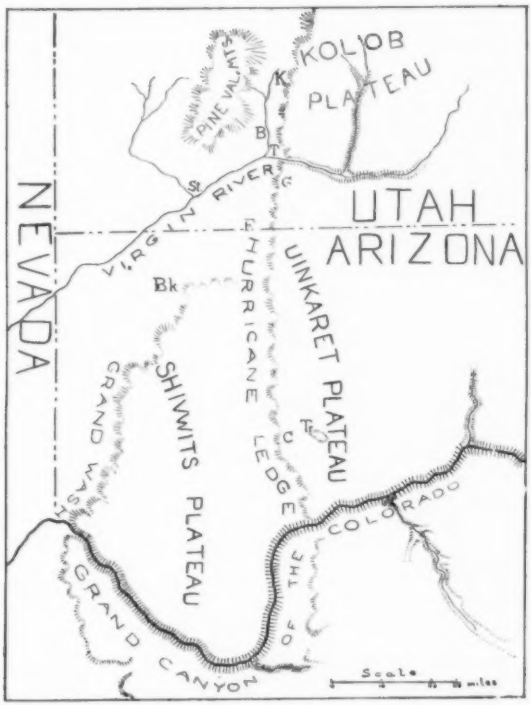
THE POST-FAULT OR CANYON CYCLE OF EROSION.
SUMMARY.

DURING the summer of 1902 the writers, under the direction of Professor William M. Davis, of Harvard University, made a study of the region around Toquerville, in the southwestern corner of Utah, on the line between the High Plateau province and the Basin Range province. Some stratigraphic work was done, and an area of about two hundred square miles was mapped. The main interest, however, centered in the relative age of the two displacements by which the plateaus of the Colorado river were elevated above the region of the Basin Ranges, and by the last of which the cutting of the Grand Canyon was inaugurated. These displacements were studied for about a hundred miles, from a point near Kanarra, twenty-five miles north of Toquerville, to the Colorado river. The older one runs almost directly south from Kanarra to the Colorado, along the Hurricane Ledge; the younger follows nearly the same course, but at the Arizona line all except a small branch turns west along a monocline and finally joins the Grand Wash fault. In this paper we shall give

in outline the history of the two displacements, reserving details of evidence and references to the work of earlier observers for a more complete report which will be published later.



Sketch-Map of part of the region traversed by the Hurricane Fault.

K—Kanarra.	G—Gould's Ranch.	Bk—Black Rock Spring.
B—Bellevue.	St—St. George.	Tr—Mt. Trumbull.
T—Toquerville.	F—Fort Pierce.	C—Coal Spring.

FIG. 1.

THE SEDIMENTARY ROCK SERIES.

The scarcity of known fossil horizons in the rocks of the High Plateau region led Dutton to divide that part of the conformable series between the known Carboniferous and the known Cretaceous into three formations on the basis of color and text-

ure and a somewhat doubtful correlation with formations in neighboring provinces. To these lithological divisions he assigned the time-names "Permian," "Trias," and "Jura." Since, therefore, these names given by Dutton apply to arbitrary divisions instead of formations known to represent the three geological periods, Permian, Triassic, and Jurassic, we prefer not to adopt them, but to use only local names for those formations whose exact age is questionable, retaining the one already in use—Shinarump—and applying new names to others of the series, as shown in the following table:

Eocene Tertiary	Conglomerate, pink sandstone and limestone.	
Cretaceous	Yellow sandstones and shales.	
Jurassic (of Dutton)	White sandstone	Colob.
Triassic (of Dutton)	Red sandstone	Upper Kanab.
	Red sandstone and shales	Lower Kanab.
	Conglomerate	Shinarump.
Permian (of Dutton)	Chocolate sandstone, Red and white shales, Red shales.	Upper Verkin.
	Gray sandstones and shales, Red shales	Lower Verkin.
Carboniferous	Variegated shales and cherty limestone	Super-Aubrey.
	Gray limestone	Aubrey.

SEQUENCE OF EVENTS IN THE TOQUERVILLE DISTRICT SINCE THE EOCENE PERIOD.

From Carboniferous to Eocene time, the history of the region is one of essentially continuous deposition, during which sediments accumulated in an almost unbroken series to a thickness of more than 7,000 feet. In contrast to this long period of accumulation, the post-Eocene history is one of vast changes—of tectonic movements that preceded and accompanied the Colorado Plateau uplift, of volcanic activity, and of profound erosion

—all of which will be briefly described below. The sequence is as follows:

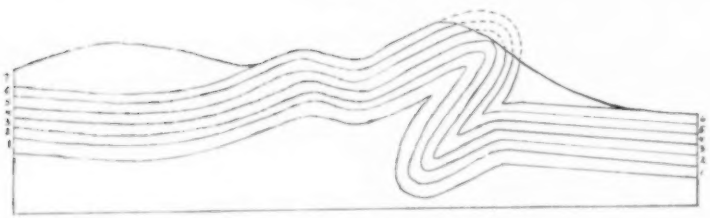
(A) Early deformation and volcanic eruptions.
(B) The first Hurricane faulting.
(C) The inter-fault or plateau cycle of erosion, ending with basalt eruptions.
(D) The latter faulting.
(E) The post-fault or canyon cycle of erosion.

DEFORMATION AND VOLCANIC ERUPTIONS.

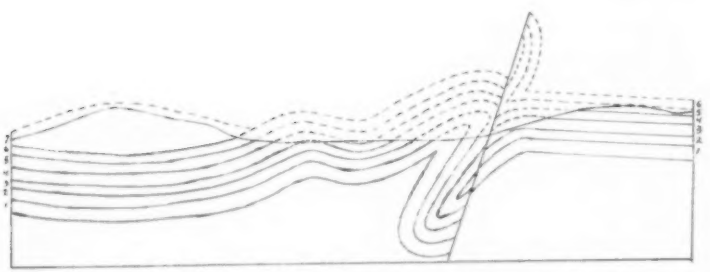
a) *Earlier folding.*—The earlier disturbance of the strata in the plateau province after their long period of quiet accumulation resulted in a number of gentle folds and flexures with slightly curved axes trending roughly north and south. In the eastern regions, according to Dutton, these were monoclinal flexures with a dip to the east by which a series of great steps was formed descending from the then relatively high Basin Range province to the lower Plateau province. In the Toquerville district the folds became intensified and took the form of well-arched anticlines and synclines. Among these more marked folds, we are chiefly concerned with the most western—a shallow syncline in which lies what now remains of the andesite mass of the Pine Valley mountains, and the most eastern—a sharp anticline that lies along the boundary between the Plateau province of relatively level strata interrupted only by the gentle monoclines, and the broken Basin Range province. South of Toquerville the sharp anticline faded out into a gentle eastward-dipping monocline, while to the north the intensity of folding increased, so that the anticline was steepened and finally at Kanarra completely overturned. The formation of these sharp folds seems to have been due to an east-and-west tangential pressure whose effects are confined to the immediate vicinity of the Pine Valley mountains.

b) *Andesite eruptions.*—The mass of the Pine Valley mountains, 3,000 to 4,000 feet thick, and twenty to thirty miles long, is composed of a heavy sheet of andesite, called by the earlier geologists a "trachyte." Wherever its base is seen, the lava lies upon a surface of Tertiary strata which seems to have suf-

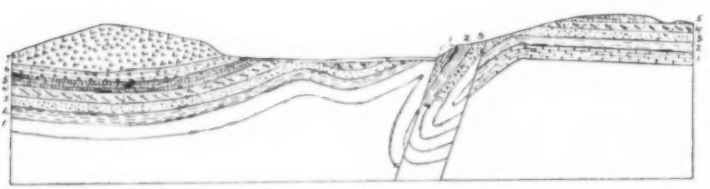
FIG. 2.



A.—Ideal section after the early folding.



B.—Restoration of section at the end of the inter-fault cycle of erosion. The dotted lines represent the sections at the beginning of the inter-fault cycle.

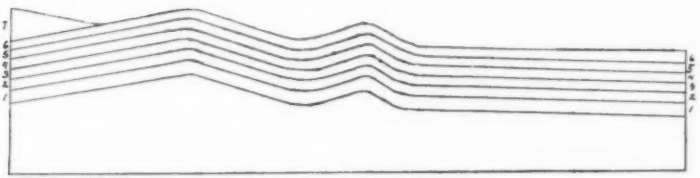


C.—Section representing present conditions.

1. Aubrey limestone.
2. Verkin shales.
3. Kanab sandstone.
4. Colob sandstone.
5. Cretaceous.
6. Tertiary.
7. Andesite.
8. Basalt.
9. Alluvium.

CROSS-SECTION OF THE HURRICANE FAULT, NEAR KANARRA, LOOKING NORTH.

FIG. 3.



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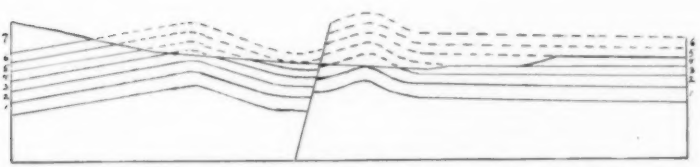
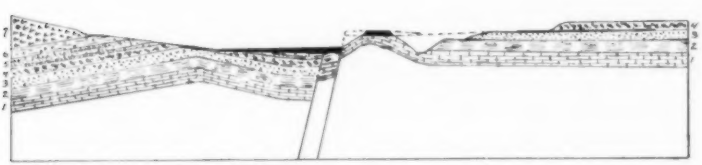


B.—Restoration of section at the end of the inter-fault cycle of erosion. The dotted lines represent the sections at the beginning of the inter-fault cycle.

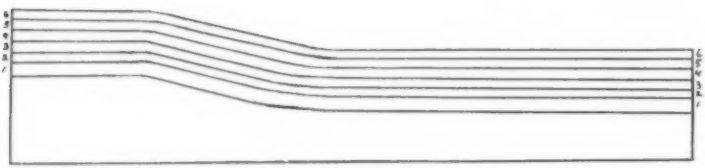


C.—Section representing present conditions.

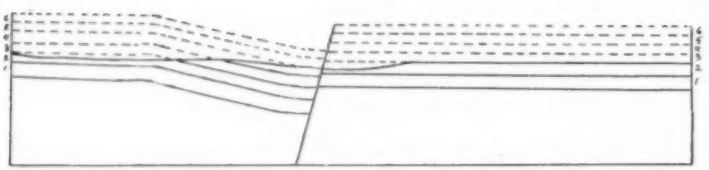
1. Aubrey limestone.
2. Verkin shales.
3. Kanab sandstone.
4. Colob sandstone.
5. Cretaceous.
6. Tertiary.
7. Andesite.
8. Basalt.
9. Alluvium.

CROSS-SECTION OF THE HURRICANE FAULT, NEAR BELLEVUE, LOOKING NORTH.

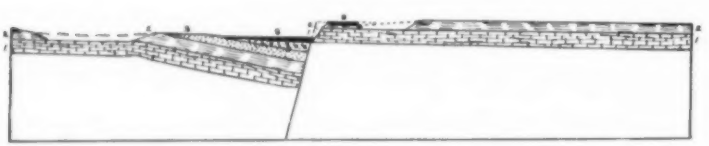
FIG. 4.



A.—Ideal section after the early folding.



B. Restoration of section at the end of the inter-fault cycle of erosion. The dotted lines represent the sections at the beginning of the inter-fault cycle.



C.—Section representing present conditions.

1. Aubrey limestone.
2. Verkin shales.
3. Kanab sandstone.
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6. Tertiary.
7. Andesite.
8. Basalt.
9. Alluvium.

CROSS-SECTION OF THE HURRICANE FAULT, NEAR GOULD'S RANCH, LOOKING NORTH.

fered little or no erosion; hence it must have been poured out before the country had been elevated above the sea long enough to allow extensive erosion—probably long before the completion of the folding.

THE HURRICANE FAULT—THE EARLIER FAULTING.

After the folding had been completed, the tangential pressure must have been relieved and a strain of another character set up. Instead of compression there seems to have been extension, whereby numerous faults were formed which followed the lines of the old folds, but moved the strata in exactly the opposite direction, so that a new series of steps descended toward the west, and the Basin Range province stood lower, relative to the Plateau province. It is noticeable that the greatest fault took place along the line of the greatest fold, and like it increased from south to north. This Hurricane fault has been traced for fully two hundred miles. For the greater part of the hundred miles which we examined from the Colorado river to Kanarra, the displacement was a true fault, with a lift of from 2,000 to 3,000 feet; but for a short distance at Toquerville it passed into a torn flexure, accompanied by an offset of three miles to the west. North of Toquerville the fault is concealed by gravel and lava, but reappears at Kanarra, where with a much increased throw it cuts the overturned anticline already mentioned. It has long been recognized that the whole displacement of the Hurricane fault did not take place at one time, but was divided between two periods. It is thought, however, that both these periods of faulting were very recent, and there is uncertainty as to the time interval between the two periods and as to the relation which they bear to the cutting of the Colorado canyon. Evidence has been found which seems to show that the first faulting is of early date, possibly in the first part of what Dutton calls the Miocene, and has no immediate connection with the formation of the Grand Canyon. The second faulting, on the other hand, is of recent date, and accompanied the single uplift which allowed the cutting of the canyon.

THE INTER-FAULT OR PLATEAU CYCLE OF EROSION.

After the first Hurricane faulting came a long period of erosion, during which the region as a whole was reduced to a condition of moderate relief and the original topography due to folding and faulting was almost entirely effaced. Near the main drainage lines there was an approach to baseleveling, and the topographic effect of hard and soft strata was largely lost. The initial fault scarp was entirely effaced, and the line of displacement came to be marked by an escarpment on that side where hard strata overlooked soft. At the same time the south-facing cliffs on the two sides of the fault retreated northward at different rates. In the more northern district, with the headwater development of a large drainage system, a rounded submountainous topography was produced. Everything indicates that the interval of erosion that followed the first faulting was very long. At the end of the period the lowlands were strewn with waste. Finally came a time of volcanic activity, when craters were formed and the old land surface was partly sheeted over with basaltic lava. It is chiefly to these basalt flows that we owe our knowledge of the two periods of faulting and of the interval between them, for they have preserved the old lowland surface. This is exposed in many places, especially where the lava sheets have been traversed by the later fault.

a) *The lava-covered Hurricane fault at Coal Spring.*— Dutton states that near the Colorado river the Hurricane fault splits into four branches, two of which must be of recent date, since they are described as cutting recent lava beds. The other two are not known to cut any lava. At Coal Spring, however, twenty-five miles north of the Colorado canyon, where no branches have been observed, an unbroken sheet of lava, showing no sign of a new fault, lies across what seems to be the main Hurricane fault, preserving a surface which is level in spite of the fact that the down-thrown side consists of soft Verkin shales and the other of hard Aubrey limestone. Since at the time of the basalt flow hard and soft strata lay side by side with an almost level surface, this part of the fault must have occurred so long before the flow that

during the interval there was time for the erosion of the surface nearly to baselevel.

b) *The lava-covered surfaces on the Shivwits plateau.*—West of the Hurricane, on the Shivwits plateau, lava is seen lying on a level surface of soft Verkin shales—rocks so easily eroded that they can assume a level surface only when close to baselevel. The wide distribution of these lava-covered surfaces points to an approach to peneplaination over a considerable area in the southwest.

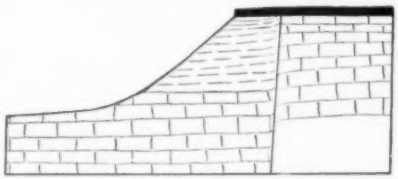


FIG. 5.—The Hurricane Fault at Coal Spring, looking north.

c) *The old fault, the old lowland surface, and the new fault.*—At several points between Fort Pierce and Kanarra, where the Hurricane fault-line is crossed by basalt flows, a displacement of two different dates is clearly shown, and it is seen that at the end of the interval between the two the relief of the region was much less than now. Where the first faulting had brought resistant strata, such as the Aubrey limestone or Upper Kanab sandstone, into contact with softer strata, such as the Verkin shales, the harder strata rose in a low escarpment, whether they lay on the heaved or thrown side of the fault. Against this the lava flowed, and thus was checked soon after crossing the line of displacement, while in other places, where the strata on the two sides of the fault were of nearly equal resistance, the lava flowed across the faults to a much greater distance. In still other cases the strata underlying the basalt are more or less tilted, but nevertheless they were reduced by erosion to a level surface that bevels the edges of the layers. Sometimes these are shales, such as those at Gould's Ranch, which under present conditions of active erosion rarely form a level surface; for they are so soft that when the overlying cap of hard strata is removed, they are at once minutely dissected into a rough bad-land topography and are soon wholly swept away, in so far as they lie above grade. In other places, as near Bellevue, five miles north of Toquerville, highly inclined

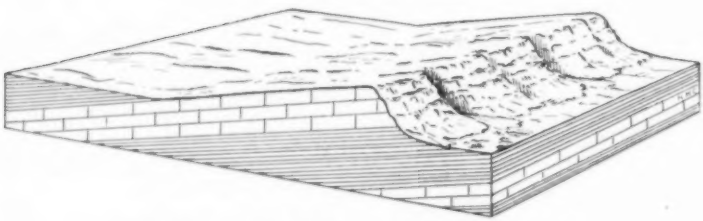
layers of alternating hard and soft strata are truncated by a level lava-covered surface, although at present hard formations lying in the same attitude form marked ridges. Surfaces of all these various types have been covered by lava flows, and have been exposed to view by a recent fault or series of faults, and the renewed erosion consequent on uplift. They all indicate that between the earlier and later times of faulting there was a long period of erosion, at the end of which the region had been reduced to relatively low relief.

d) *Mature topography of the Colob plateau.*—Two miles north of Kanarra coarse Pleistocene gravels rest on the rather level surface formed by the dissection of the inverted strata between the old and new faults. On the gravel lies lava which seems to have come from the high plateau of Colob, east of both faults. The lava probably did not cross far west of the old fault, because it soon encountered the down-thrown Aubrey limestone which stood relatively high on account of its hardness. The recent faulting depressed the limestone area and allowed it to be covered with deep alluvium. This displacement also gave rise to a renewal of erosion by which the lava on the edge of the up-thrown block has been dissected into mesas and buttes, although back from the borders on the main mass of the maturely dissected plateau the revived activity of erosion has not as yet penetrated. The lava there lies on a surface of just the same sort as that which still characterizes the neighboring parts of the plateau which are not protected by a basalt covering. So it seems probable that the topography of the central mass of the plateau, even where it has not been protected by lava, is almost the same as that which prevailed previous to the basalt flows and the second faulting. The rounded mountainous hills, rising to a height of two or three thousand feet, the graded slopes, well-established drainage, and broad valleys, are strongly in contrast to the precipitous slopes and new aspect of the peripheral regions, and seem to represent the conditions previous to the second uplift.

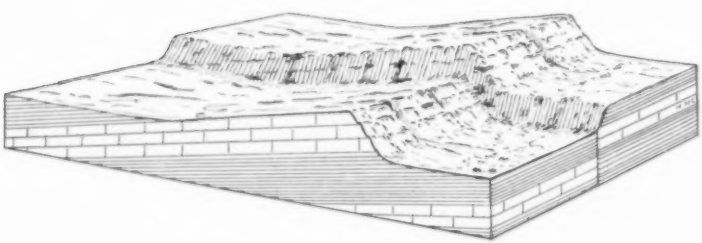
e) *Differential recession of cliffs on the two sides of the old fault.*—Still another line of evidence shows that there have been two periods of faulting separated by a considerable interval of ero-

sion. The unequal recession of outcrop cliff on the two sides of a fault is a principle that has already been discussed in connection with the plateau region. It was recognized by Powell that when a set of outcrop cliffs is cut by a transverse fault the cliffs on the up-thrown side will be subjected to more powerful weathering and erosion than those on the lower side; consequently they will retreat faster and the outcrops on the two sides will in time become discordant. Professor Davis has recently pointed out that the amount of discordance gives a measure of the length of the period of erosion that succeeded the faulting. In the plateau region the apparently level strata, which really dip slightly to the north, form steep south-facing cliffs which are gradually worn northward along their gentle dip. Since the original Hurricane fault took place the Kanab red sandstone cliffs on the eastern side have retreated over fifteen miles farther than their low-lying counterparts on the western side. Inasmuch as this distance represents, not merely the whole amount of retreat, but the excess of retreat on one side over that on the other, the time during which the process went on must have been very long.

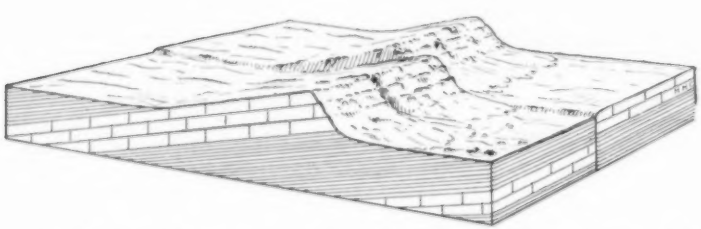
f) *General review of the topography at the end of the inter-fault cycle.*—The fragments of old surface that are preserved under the lava sheets generally belong to lowland topography, and have been examined chiefly in the subsequent valley that seems to have followed the old fault line, first on one side, now on the other, according as the strata were hard or soft. The mature mountainous hills of the old still unchanged plateau preserve the ancient form of the uplands. Between the highlands and the lowlands were long graded slopes which have now been revived into steep, rapidly receding cliffs of naked rock. All this signifies a long period of erosion—so long that the main valleys were reduced nearly to baselevel, although the more remote regions to the north were still somewhat mountainous and there was still considerable relief in the intermediate regions. At that time no Grand Canyon can have existed, although the Colorado river must of necessity have been a very important feature in the topography. Its valley must have



A.—Unfaulted block showing a continuous line of cliffs.



B.—The same block cut by a north and south fault.



C.—The same block after erosion has almost obliterated the fault scarp. The cliffs on the eastern or upthrown side of the fault have retreated much farther than those on the down-thrown side.

BLOCK DIAGRAMS ILLUSTRATING THE DIFFERENTIAL RECESSION OF CLIFFS ON THE TWO SIDES OF A FAULT.

FIG. 6.

been like those of its tributaries—a broad open depression where the river flowed on an extensive flood-plain close to base-level. Near the end of this cycle of erosion there was extensive aggradation, forming the heavy gravel deposits of Kanarra, the Virgin river, and the Grand Wash. Then came an abundant outpouring of basalt from many craters, especially in the region

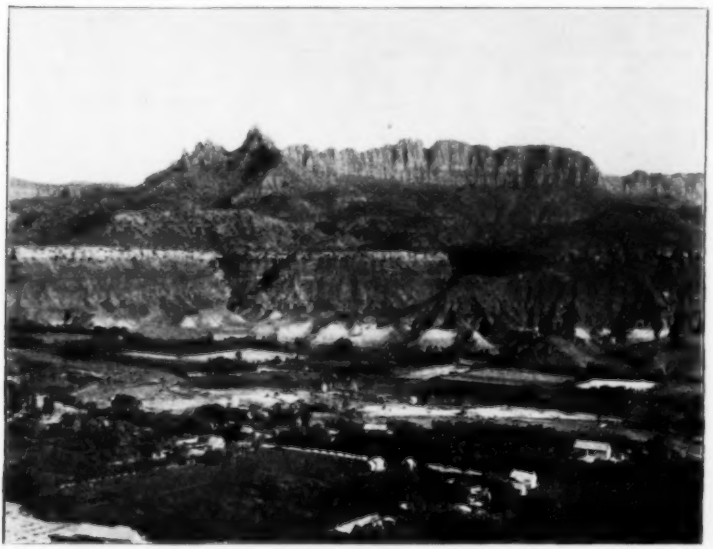


FIG. 7.—View south across the valley of the Virgin river at Rockville. The sharp cliffs of Red Kanab sandstone in the background rise 3,000 feet above the river. Below them are soft lower Kanab shales, the rapid weathering of which has undermined the Upper Kanab, causing the great landslides that are seen lying on the Shinarump platform which extends across the middle of the picture. Below the Shinarump the soft Verkin shales are minutely dissected into a bad-land topography, whose roughness and aridity contrast strongly with the irrigated fields of the Mormon village of Rockville on the flood-plain in the foreground.

that was nearest baselevel; and thus a new and very durable element was introduced into the topography.

THE HURRICANE FAULT—THE LATER FAULTING.

The newer displacement, like the older one, changed at Toquerville from a fault into a flexure. South of Toquerville,

however, the displacement continued as a true fault to Fort Pierce, beyond which it split. One part, which followed the old fault line, seems to have greatly diminished, but, as indicated by the broken lavas that Dutton describes, was of considerable importance where it crossed the Grand Canyon. The other passed into a long gentle monocline, and, leaving the old

FIG. 8. — Mukuntuweap canyon, looking north. The sky-line on the right shows a portion of the mature topography of the Colob plateau. On the left the Temples of the Virgin, of red Kanab sandstone capped by the white cross-bedded Colob formation, rise 2,500 feet. They have been carved by the erosion consequent upon the uplift which introduced the canyon cycle. The level foreground is a lake plain, formed when the stream was obstructed by landslides similar to those seen in Fig 1.

Hurricane fault line, bent to the southwestward until at Black Rock it joined the Grand Wash fault. This, like the Hurricane, is a young displacement following the line of an old one, as is shown by the relation of lava flows to the strata preserved under them. The line of dislocation, then, which separated the uplifted Plateau province from the Basin Range province

reaches the Colorado river in much the greater part by the Grand Wash, and only in small part by the Hurricane. It is to this great uplift, limited on the west by the Grand Wash and Hurricane faults, that we owe the inception of the canyon cycle of erosion and the cutting of the Grand Canyon of the Colorado.

FIG. 9.—The Hurricane escarpment just north of Toquerville, as seen from the northwest. The Aubrey escarpment, 2,000 feet high on the left, diminishes as it passes into the torn flexure, which is shown in Toquer hill, the black lava-covered hill in the middle distance. Beyond this are the Shinarump capped mesas of Verkin shales that lie east of Gould's ranch.

THE POST-FAULT OR CANYON CYCLE OF EROSION.

During and since the later uplift there has been a cutting of canyons in the hard strata, and a general stripping of unprotected soft strata. In the Plateau region erosion has gone just far enough to emphasize very successfully the topographic value of hard and soft strata. Thus, along the fifty miles of the Hurricane south of where most of the new displacement turned westward, the rapid wearing away of weak Verkin shales on the western side of the old fault line has left the hard Aubrey limestone on the eastern side as an erosion escarpment so strong that Dutton took the whole of it for an actual fault scarp of recent

date. At Coal Spring, where the basalt flowed west across the old fault line onto the Verkin, the weak shales were locally protected, so that the modern cliff front at this point is west of the old Hurricane fault line. Of this 1,800-foot escarpment all but a few hundred feet is the product of erosion on the line of the old fault during the canyon cycle. There could be no better illustration of the progress of erosion since the later faulting than this, which shows that the existing cliff has been shaped almost

FIG. 10.—Sugarloaf mesa, on the edge of the Hurricane escarpment, west of Gould's ranch. A small basaltic cap protects a few hundred feet of Verkin shales, which recent erosion has elsewhere stripped off to the level of the Aubrey platform seen in the foreground.

wholly by erosion, working under the conditions imposed by the old fault, the erosion interval, the basalt flows, and the recent uplift.

SUMMARY.

The post-Eocene history of the Toquerville district has been characterized by two periods of upheaval, separated and followed by periods of relative quiet. In the first period, which was doubtless of great duration, with an unknown amount of erosion, occurred the original folding, the eruption of andesite upon a surface, but slightly, if at all, dissected, the reversal of the direction of deformation, and the earlier faulting. In the Kanarra

section the fault followed the greatest of the folds, while in the portion south of Toquerville it traversed nearly horizontal plateau strata. These disturbances introduced the inter-fault cycle of erosion—a long period of comparative quiet, during which the outcrop-cliffs on the two sides of the fault receded northward at different rates, and the whole country was reduced to a degree of relief far less than the present. The southern region approached peneplaination, while toward the north the surface rose into graded mountainous hills separated by broad valleys. The close of this period was heralded by aggradation in the main valleys, and by extensive lava flows. In the second period of upheaval came the uplift of the Plateau province, marked by a displacement along the Hurricane and Grand Wash faults. The last period, or Grand Canyon cycle, has seen the cutting of numerous deep canyons and the stripping of large areas of soft strata; but its main work as a cycle of erosion is as yet only begun.

ELLSWORTH HUNTINGTON.
JAMES WALTER GOLDTHWAIT.

STUDIES FOR STUDENTS

THE CRITERIA REQUISITE FOR THE REFERENCE OF RELICS TO A GLACIAL AGE.[1]

INTRODUCTION.

THE criteria herein discussed are given shape with special reference to human relics because these possess pre-eminent interest, but they are equally applicable to all relics, whether they are those of man, of animals, or of plants. The criteria are also defined with special reference to America, though they are equally applicable to the Old World. This is not by any means to say that the facts are the same on the two continents.

The theoretical grounds for assuming the existence of man *somewhere* on the globe in preglacial times are very strong. In Europe the evidences of man's presence during some of the interglacial periods appear to be substantial. So far as America is concerned, the question is purely one of fact to be determined strictly by scientific evidence. There seems to me little or no legitimate ground for a predisposition to accept or to decline to accept a glacial or preglacial antiquity for man in America. The existence of the race upon the eastern continent in glacial times does not carry any special presumption of its existence upon the western continent at that time. The belief that man originated upon the eastern continent rather than upon the western has something of strength in biological considerations, and is supported by the preponderance of existing geological evidence. If man originated in the Old World, the time when he migrated to the New is an open question until it is closed by thoroughly sound evidence, precisely as it is in the case of the migration of any of the mammals which originated upon the eastern continent and is now a denizen of the western. If it is

[1] Read in abstract before Section E, A. A. A. S., Washington Meeting, January, 2, 1901.

a more important matter to us, it is the more important that its evidence be sound. The notion that the life-history of one grand division is to be "brought into accord" with that of another is a perilous guide. In certain general aspects, the life-history of the several subdivisions may indeed have points of accord, but in its special phases divergence is quite as much the rule as concordance. In any given case, the probabilities are that a given form originated in one grand division rather than in all, and that more or less time elapsed before it migrated to distant regions. There is therefore no presumption that all the early stages of evolution will be found on all the continents.

Nor do I see any good scientific reason to desire one result rather than another. I see no scientific grounds for a predisposition to match European antiquity by American antiquity, or the European stages of evolution by American stages of evolution. It is quite as much in the interest of ethnological science, so far as I can see, to limit the duration of the human species on the western continent as it is to extend it. Given three or four great divisions of the earth's surface in which a species may develop in measurable independence, probably as much, and perhaps more, can be learned from the introduction of the species into these several divisions at different and rather widely separated intervals, as can be learned by its introduction into all of them simultaneously, or in close succession. Evolution through periods of different lengths in the different divisions would probably show at least as much, if not more, of the rate and nature of development as would evolution for equal periods in all the divisions. We shall probably learn quite as much of the great lessons of human evolution if it shall be shown that the American races have developed since the glacial period, so far as they are endogenous, as if it shall be shown that the period reaches back to one or another of the interglacial epochs or to the preglacial period. In any case, to the ideal scientist, it is purely a question of fact to be settled by demonstrative evidence. Our concern here is what constitutes demonstrative evidence.

Evidence to be sought in the glacial formations themselves.— Grounds for assigning man to a glacial period are to be sought

primarily in the glacial formations themselves. This is the principle we recognize in the assignment of a pebble or a bowlder, and it should hold good for human relics. A few years ago two of our most experienced glacialists and three younger associates reconnoitered seven states, and then held their conclusions in abeyance for several years, because they were not fully convinced that certain crystalline pebbles in certain gravels outside the true glacial formations were or were not truly glacial in origin. Had these pebbles been found in glacial deposits, their reference would not have caused a moment's hesitation. It is only applying to human relics the standards adopted by careful glacialists relative to pebbles, to insist that there is a profound distinction between the value of evidence from the direct glacial deposits and that from derivatives or secondary deposits.

I. EVIDENCE FROM PRIMARY GLACIAL DEPOSITS.

There are three good classes of cases connected with the primary glacial material:

1. The first of these is *imbedment in the till sheets or the moraines.* If the identification of the glacial deposits and of the relics be beyond question, relics found imbedded in the true glacial deposits constitute very strong evidence of contemporaneous or previous origin. There is some danger of error even here, however. Secondary deposits of till are liable to be confused with true original deposits. Slides, creep, and wash not infrequently bury recent material under what at first seems to be true bowlder clay. Many a time has the experienced and alert glacialist had occasion to use the most careful circumspection to avoid error in assigning wood, buried soils, and other fossils to a glacial or interglacial age, whose burial proved on close inspection to be secondary and utterly worthless for chronological purposes. There are also incidental intrusions by means of burrows, root holes, cracks, etc., which require elimination. If all these are excluded by expert observation *controlled by unrelaxing alertness and persistent caution*, evidence of a high order of value is theoretically derivable from the tills and the moraines.

I say "theoretically derivable," because no fully authenticated case of this kind has been presented as yet, so far as I know.

2. *Evidence from assorted drift included in till and moraines.* — Relics found in gravels or sands interbedded with true bowlder clays, when they are clearly of immediate glacial derivation, furnish nearly as good evidence as relics in the bowlder clays themselves, but their identification requires more circumspection.

3. *Evidence from kames and eskers.* — So also relics found in true kames or eskers may furnish good evidence if the sources of error are sufficiently avoided, but still more caution and alertness are required here.

Confirmatory evidence in these cases. — Glacial *striation*, besides being a source of evidence in itself, may afford supplementary evidence in these cases and may serve as a check on the sources of error previously noted. Unmistakable glacial striation may even make good what would otherwise be worthless evidence. For example, a well-striated bone found in secondary till might be accepted as good evidence of glacial antiquity, whereas if unstriated it would have to be excluded because the rearrangement or disturbance of the till would vitiate its trustworthiness. Striated stone implements must, however, be received with great caution, for, in the first place, stones that had long before been striated may be used in the construction of implements without obliterating all the striation, and, in the second place, use may give rise to grooves and scratches very like true glacial work. Erroneous identification of striæ are by no means uncommon in the history of glacial geology.

Combined evidences. — When well-authenticated striation is combined with imbedment in original glacial deposits, the evidence reaches its highest value. We have, however, so far as I know, no such cases as yet in America.

The culminative value of repetition. — The evidential value of *good* cases rises rapidly with their multiplication, for the doubts that might legitimately arise in a single case notwithstanding all precautions against error are effectually reduced by additional good cases. But, true as this is, no amount of multiplication of

bad cases makes a *good* case. On the contrary, the multiplication of weak and false cases throws doubt on all and is a legitimate ground for rejecting all. The first step toward a firm ground of confidence is the sweeping away of all bad cases of the past and the effectual barring out of all new ones.

The interpretation of imbedded and striated relics. — Human relics found in the true glacial deposits, whether striated or not, do not necessarily tell whether man lived in the immediate presence of the ice or whether he had lived in the region *before* the ice invasion. (1) The relics may have been picked up from the preglacial surface by the ice as it pushed over the region, just as rock fragments and earthy matter were, or (2) they may have been dropped on the ice or at its border or on the moraines in the presence of the ice. If the relics are found to be associated with other organic remains that imply a warm climate, the former inference is favored; if the associated organic remains imply a cold climate, the latter inference is the more probable, but as all the relics are disturbed, the inference is not firm in either case. If human bones are found that show evidence of long weathering and subsequent striation, there is good ground for inferring the existence of man in the previous interglacial or preglacial period. The absence of weathering would not be equally good ground for the opposite inference, because certain kinds of burial exclude weathering.

A demonstration that man existed before a given glacial invasion would imply his existence during it in some part of the globe, and presumably in the grand division in which the relics were found, but a closer interpretation than this requires special evidence.

II. EVIDENCES FROM THE INTERGLACIAL DEPOSITS.

The interglacial deposits include those surface accumulations that were formed in the interval between the ice invasions of a given region. They are chiefly soils, muck, peat beds, and various wash products, including fluvial, lacustrine, and occasionally marine clays, silts, sands, and gravels. There were similar deposits outside the glaciated regions, but as these were not

buried by later glacial deposits, they cannot generally be connected demonstrably with the glacial invasions, and are therefore not here included. The abandoned surface of a recently glaciated region furnishes excellent conditions for the burial and preservation of relics, for it usually presents an uneven surface which becomes dotted with ponds, swales, and ungraded valleys, so that erosion and deposition are the natural order of things. The basins furnish alluring grassy meadows and the ponds offer enticements to drink, while the bordering bogs and springy grounds lie in wait to mire the weak and unwary, and clayey inwash from the higher ground provides a preservative burial. Although the interglacial beds were subject to much disturbance and to removal during the succeeding ice invasion, they were preserved in a singularly large number of cases, and fossils, often in the most excellent state of preservation, are sometimes found in them. The delicate tissues of mosses are occasionally admirably retained.

The fossils of these beds have the further merit of definite fixity in time and localization. In this respect there is not the uncertainty of the previous class. The imbedded plants and animals lived subsequent to the deposition of the underlying drift and previous to that of the drift above.

But even here there is a source of some vagueness, though it is not radical. It is a not uncommon practice of glacial geologists to include among the interglacial formations gravels, sands, and clays, which overlie an earlier bowlder clay, even though it may be quite possible that these were formed in the last stages of the preceding glacial epoch, and are indeed nothing but the glacio-fluvial deposits of that epoch. Of course, this is not done by the discriminating glacialist where the case is determinate. But usually the case is not determinate, and then the interglacial epoch is given the benefit of the doubt. Any error in date arising from this source would be a conservative one, since the relics are, at the worst, only referred to a slightly later date than they are entitled to.

Sources of error connected with interglacial deposits.— The liability to error here is not very serious, if due circumspection is exercised.

There may be false identifications of the overlying and underlying glacial deposits and of the interglacial beds themselves, and there may be misinterpretations arising from that *bête noire* of the incautious glacialist, secondary displacement and rearrangement, but a duly trained and fairly skilful worker should avoid all these. These interglacial beds present by far the most promising field for the demonstration of the presence of man in America during the glacial period, if he really lived here then. No good case of relics from them, however, has yet been presented, so far as I know.

III. EVIDENCES FROM ASSORTED DRIFT LYING UPON OR OUTSIDE OF THE TRUE GLACIAL SERIES; RIVER DEPOSITS ESPECIALLY.

Nearly all the relics upon which the presence of man in America in the glacial period has been claimed are from deposits of this sort, and they hence deserve critical attention. For the greater part, these deposits are valley trains or frontal aprons of gravel, sand, and silt. There are three different classes of deposits of this kind that are remarkably similar in their general characters, but which must be positively distinguished from each other before any safe conclusions can be drawn. This is a work of grave difficulty, and in many cases I know of no way in which it can be successfully done. One of these classes is glacial, and the two others are postglacial. Before relics in these can be referred to the glacial period, it must be shown that the deposit bearing them belongs to the first class, and certainly does not belong to either of the other two.

1. The first class consists chiefly of gravel, sand, and silt borne out from the ice by the glacial waters and deposited along the glacial waterways. These are truly glacio-fluvial and strictly contemporaneous with the ice action. Contemporaneous burial in these means of course a glacial age.

2. The second class consists of sand, gravel, and silt of almost identical composition and structure formed by postglacial waters working on the drift surface and washing out from it the same class of material that the true glacial waters did and spreading it along the valleys in an almost identical way. More than this,

the deposits of this class are likely to be the uninterrupted successors of those of the previous class, and hence to overlie them conformably. There is therefore the most extreme difficulty in distinguishing the two under most conditions. In the case of outwash aprons and certain abandoned valleys, and in other particular cases closely adjacent to the ice edge, the discrimination can be made, but in most cases at a distance from the ice edge I know of no certain means by which it can be done. The postglacial modified drift should theoretically be somewhat more weathered than the true glacio-fluvial drift, but the amount of weathering which took place after the ice retreated and before the material was carried away and deposited would not in most cases be great, and what there was would largely be worn off in the transportation preliminary to the deposit of the material as modified drift. It is therefore an unavailable criterion.

3. The third class consists of the first and perhaps the second class reworked by the postglacial streams after they exchanged their *aggrading* habits to *degrading* ones. In this class the material is identical, or essentially identical, with that of the preceding classes, since it is the same material reworked, with some addition from the same general source, the drift of the region, and its structure is so closely similar that a careful glacialist would hardly venture to discriminate between them. The topography, especially the relations of the deposits to the terrace systems, where such exist, often aids in forming an impression of the probabilities, but in most cases it cannot go much beyond that.

Scour-and-fill.— The process which is most concerned in introducing the confusion of this third class is *scour-and-fill*, one of the most obvious processes in all geology, but one of the most neglected. It is a very familiar observation, if we but recall it, that every active stream has shallows and deeps, and that the differences in depth of water are very considerable. It is also certain that these are constantly changing, and that with the shifting of the course of the river they undergo complete obliteration and are replaced by flood plains. The whole bottom of the valley, so far as involved in the range of the river's meanders and other shiftings, is subject to this alternate erosion

and filling. It is equally clear that any relics that may come within the river's action, except such as float, are liable to be buried to depths equal to the difference between the height of the flood plain and the depth of the deep holes in the bottom of the river. In the great rivers, this range not infrequently reaches 100 feet and more, and is very commonly three and fourscore feet. In many cases the scour reaches the rock bottom, and at such places the entire bottom deposit is undergoing reworking, and modern relics may be introduced into any of its depths. This phenomenon is most strikingly displayed in the Missouri river, where the engineers tell us that transient scour often reaches bed rock, and that the scooping out and filling up follow one another with almost seasonal frequency. So pronounced is this action that the impression has been given that the *whole bottom deposit is being shifted turn-by-turn down stream.* While this may be an overstrained deduction, it is supported by a great mass of very important facts, too much neglected. The erosion of the rock bottom of most streams is accomplished by such alternate shiftings of the loose bottom material. At any one time, this loose material covers most of the bottom of most degrading streams even, and the wear on the rock bottom is accomplished first here and then there by the shifting of the covering of loose material. In practically no streams at all, except perhaps mountain cascades, is the whole bottom exposed to erosion at the same time. In the drift-filled bottoms of the great branches of the Mississippi system, it is wholly within bounds to regard at least the upper 40 or 50 feet of the deposit over which the river meanders as subject to scour-and-fill and to entertain the suspicion that the deeper portions down to 100 feet or more may be similarly affected. To make out a good case for the antiquity of relics buried in such a deposit seems well-nigh impossible.

Scour-and-fill affects more or less every portion of a river deposit that has formed a part of the channel bottom at any time in its history. This action does not usually much affect the flood plains while they *remain such.* There are exceptions even here, and not very infrequent ones, but scour-and-fill is not

normally an effective mode of action on the flood plains. And so a portion of a fluvial plain that has never been occupied by the river channel, but only by its upper floods, if indeed there be such a portion, would not be greatly open to the suspicion of having been reworked by scour-and-fill. But every part of the flood plain that is occupied at intervals by the stream's channel is subject to scour-and-fill, during the whole period of such periodic occupancy, and the contents of its deposits are subject to all the uncertainties of origin already pointed out.

Unequal effect on aggrading and degrading rivers.—Scour-and-fill affects both aggrading and degrading rivers, but it does not affect them equally. In aggrading rivers, especially those rapidly and declaredly building up their bottoms, as in the case of typical glacial streams, the river is usually broken up into a plexus of branches by the successive filling up of the channel bottoms and the diversion of the streams. Deep scour-and-fill is not a pronounced habit of such streams. Already overburdened with detritus, they have not that reserve capacity for taking up a new burden that clearer streams have, and their division into numerous weaker branches takes away the cumulative power which the combined and concentrated current of the clearer degrading streams possesses. The action reaches its greatest efficiency, it would seem, when the whole stream concentrates its full force in a limited portion of its channel, and when it is free to take on temporarily a large additional burden of detritus. The action is greatest at the turns of the streams where the arrested or diverted momentum of the current develops a powerful rotary movement of the water.

Breadth of action in the great streams of the glacial area.—Now this reworking of the fluvial deposits along the courses of the Missouri, the Mississippi, the Ohio, and many of the other large streams in the glacial area, occupies or has recently occupied nearly or quite all the space between the bounding bluffs. Here and there within protected recesses, or in other favored spots, there may be a few exceptions, but in most of these cases even it may be difficult to prove that the remnant deposits were not reworked in postglacial times, though somewhat remote ones. The only

cases that can be held to be exempt from this suspicion are terraces that can be shown to be remnants of the original glacial flood plain and can be discriminated demonstrably from remnants of some one of the many flood plains that succeeded this original one in the history of the subsequent erosion of the valley deposits. Except quite near the former ice edge, where the true glacial plain is demonstrably connected with a distinctive head at the ice edge, this discrimination is practically impossible. In many cases the terraces themselves bear characters that awaken the suspicion that they do not represent the true glacial plain. In many cases they do not stand at consistent heights, and in many others they bear a suspicious configuration.

In the immediate vicinity of the ice edge from which the gravel trains originated, it is possible to identify with confidence the original glacio-fluvial plain, if due circumspection is exercised, but I think that it is only within a few miles of the parent ice border and in a few special cases of other types that the conditions are favorable for a trustworthy reference of buried relics, to the ice age.

Adjustment plains as sources of deception.—The chief source of misplaced confidence by even glacialists of ability and experience lies in mistaking a *post-glacial adjustment plain* for a *true glacio-fluvial plain.* It is a familiar observation that the true glacial flood plain rises rapidly as its head at the ice edge is approached. There is for this the obvious reason that the waters issuing from the ice edge are usually heavily overloaded with detritus, and on this account they build the stream bottoms up to a high gradient. When the ice retires and the waters become purer a readjustment of the gradient follows. This is accomplished usually by cutting down the high gradient at the head and redepositing the material so removed at some point of lower gradient below. Later this adjustment becomes the subject of a new adjustment by which the gradient is again lowered in the upper part, and the material removed in so doing is redeposited still farther down the valley, and so on by a progressive series of partial readjustments until the whole gradient

of the valley has been brought into working harmony. The earlier readjustment plains may often be seen a few miles below the terminal moraines on which the true glacio-fluvial plains take their origin. At such points the valley is often filled from bluff to bluff by a smooth plain of gravel of glacial aspect, and the impression is apt to grow into great strength that this is the true glacial flood plain. But as it is traced up toward the moraine, terraces of higher altitudes and higher gradients are seen to rise on the sides of the valley, and grow in strength and continuity until they clearly disclose the earlier plain of which they are the remnants, and this plain is found to merge into

FIG. 1.—Illustration of the successive formation of a true glacio-fluvial and two adjustment plains. *M*, moraine at which the true glacio-fluvial plain heads; *H*, head of the valley train of true glacio-fluvial gravel: *AAA* down-stream portions of the same; *BBB*, first adjustment plain, lower than glacio-fluvial plain at the right, and higher at the left; *CCC*, second adjustment plain crossing the horizons of both the preceding. The portions of the adjustment plains at the left are liable to be mistaken for the true glacio-fluvial plain.

the moraine, while the other plain of lower gradient is found to connect with a channel cut through the moraine. In such a declared case, it is clearly seen that the plain of lower gradient (and lower position at the moraine) is the higher plain a few miles down the valley, and is there altogether likely to be taken for the plain of true glacial date. Still farther down the valley a yet later adjustment plain may be uppermost and prevailing, and so liable to be misinterpreted. Errors of interpretation of this kind are liable to be made within five miles of the moraines on which the gravel trains head.

Amount of the errors.—At such a distance probably the amount of error in time may not be great, but we really do not know how fast or how slow such a readjustment takes place. While geologically rather rapid, it may be rather slow in terms of human migration. In the nature of the case, the farther the locality is

down the valley from the head of the gravel train, the later is the readjustment.

It will be seen from this that even where the valley train of modified drift is well preserved and is clearly the highest plain of the kind in the valley at that point, it may be an error to refer it to strict contemporaneity with the ice presence. For aught that we know, it may have been formed several hundred, and perhaps a few thousand, years after the ice retired. The difference is trivial in geologic terms, but it may be of much moment in human history. No readjustment of this importance, I think, is known to have taken place naturally during the invasion and wide occupancy of this continent by the white race. We should have to draw our geologic lines closer than this to fix the not unimportant period of our people by geologic data.

Without going farther into the refinements of the case it appears—

1. That even where the valley train is well preserved and constitutes a broad plain or extensive terrace, and is the highest deposit of the kind in the valley at that point, and its material is indistinguishable in kind and structure from true glacio-fluvial material, there is danger of appreciable error in referring it to the ice age. In the case of relics imbedded in it there are the added dangers already referred to, unless some special evidence excludes them.

2. That where nothing but isolated terraces are involved much doubt as to the correlation of these is liable to arise legitimately.

3. That where the terraces are below the maximum height for the locality, there is definite ground for suspicion.

4. That in all cases where there is any chance that the river in its degradational stages has meandered over the locality, the possibility of scour-and-fill gives grounds for serious suspicion. The possibilities of natural deep intrusion by this prevailing process are only limited by scores of feet; indeed, only by a hundred feet, or more.

The general purport of these combined sources of possible error is to emphasize *the very unpromising character of valley grav-*

els as a source of really good evidence of man's glacial age. It is clear that these gravels are liable to present many misleading cases, and this is a reason for special caution on the part of geologists, while it is a sufficient ground for anthropologists to withhold the acceptance of supposed evidence of this class until it shall be conceded to be demonstrative by the most critical glacialists.

IV. FLOOD-PLAIN DEPOSITS.

The preceding discussion relates to clear, well-stratified gravel, sand, and silt deposits of the same composition as the true glacio-fluvial formations and of the same general aspect and part of the same complex train of assorted drift deposits. Over these deposits of glacio-fluvial aspect there is usually spread a layer of more or less structureless silt, with intermixed sand and gravel, in which human relics are not infrequently found. There is scarcely a presumption that these surface deposits are of glacial age. They are generally the products of the river floods formed during the stages when the river is sinking its channel into the underlying gravel plain, a stage which is usually reached some time after the glacial floods ceased their work of aggradation. Usually it is not until after the work of adjustment following the close of the glacial stage has been completed, and probably in some cases only after a period of aggradation, due to the special erosion of the drift succeeding the retreat of the ice, has passed.

All flood-plain surfaces of this class should be excluded from ground likely to give any good evidence of contemporaneity with the ice age.

V. BLUFF-BORDER ACCUMULATIONS.

There is a class of deposits closely correlated with river bluffs that have played a part in the discussion of man's antiquity in America. In these cases the bluffs have been cut from plains of glacial or glacial-like gravels, and the deposits on the borders of the bluffs have on this account been referred to a glacial age. There are at least two classes of these. The first is a form of the preceding flood-plain surfacing. As is well known, where a river overflows its bordering bluffs and banks, its largest,

and in general its coarsest, deposits are likely to be made on their borders where a low ridge or natural levee is built up. This takes place while the stream is still overflowing its bluffs at high stages. But these may remain on the bluff border after the stream has cut its valley so deep as to cease this overflow. This, of course, depends upon the chance whether the river encroaches upon its bluffs at the given place or not. Such deposits and their contents are to be referred normally to an advanced stage of degradation of the river, and hence presumably some considerable time after the glacial aggradation of the valley and the sequent adjustments had ceased. The strong presumption is against the reference of these deposits or their contents to a glacial age.

The second class are formed by wind action conditioned by the bluff itself, and hence are subsequent to the formation of the *bluff*. The sloping face of the bluff directs upward the wind that blows against it from the valley, and this upward current lifts the horizontal current at the level of the top of the bluff and causes an eddy of relatively quiet air just back of the bluff edge, in which sand, and such pebbles as the intensified wind at the bluff edge may be able to roll back, to lodge and form a low flat ridge. Mr. Knapp has observed many of these in New Jersey and assigned to them their true cause, as it would seem. Their relationship to the bluff edge and to the strong winds leaves no serious ground to doubt their origin. As these are later than the bluff and the bluff is later than the gravels in which it is cut, and as these gravels may even be later than the close of the ice invasion, there is no ground for referring relics found in such deposits to the ice age.

VI. DERIVATIVE FORMATIONS.

These have been touched upon at several points already, but as they are the special danger-ground of the unwary and are liable to deceive the very elect, some further special notice seems required.

Inverted deposits.— The reversal of the order of deposition in the *process of bluff formation* is a special instance. A river

that has depressed its channel deeply into a plain of glacial or glacial-like gravels develops its bluffs on either hand, and from time to time forces them back by under-cutting at its aggressive bends. This action for the time is likely to develop nearly vertical bluffs; at least steep bluffs. While the cutting is in progress, the top of the bluff falls into the river and its surface material, with whatever human relics may lie on it, is liable to be strewn along the stream bed under the bluff and beyond. When the stream shifts its course and the cutting ceases, the top still continues to fall or slide or be washed to the bottom. In this way the upper part of the bluff recedes, while the lower part is built forward until a slope of stability is reached. In the process some of the surface material is quite certain to become deeply buried if the bluff be high. This has been amply pointed out and illustrated by Holmes.[1]

As already remarked in other connections, deposits are subject to slumps, creep, and other displacements that introduce chances of error that must be carefully eliminated.

So also loess bluffs are notably subject to creep in successive large masses, which preserve their internal integrity, and hence are liable to be regarded as undisturbed. This process is grandly displayed at Vicksburg, where the displacements range through some 200 feet.

VII. RECOMPOSED SECONDARIES.

Misleading as the inverted drifts may be, they are less illusory than some recomposed secondaries. The leading class here consists of *subærial aggradation accumulations.* Nearly every valley is subject to oscillations in the relative activity of erosion and of transportation within its own limits Sometimes the derivation of material in one part of the valley exceeds transportation in another part, and deposition is the result. The consequence is wash in one part and lodgment in another. These oscillations may be due to changes in the precipitation, in the vegetal clothing, in the relative stages of erosion, in the relations to other streams and to other causes. In these cases the material is derived mainly from the steeper slopes or steeper ravines,

[1] HOLMES, JOURNAL OF GEOLOGY, Vol. I, No. 1, 1893.

and is chiefly deposited on the lower slopes or in the flatter portions of the valley. The secondary deposit is therefore chiefly a low slope deposit and a valley-bottom deposit. It therefore conforms to the natural configurations of the valley; indeed, the new deposit is the very element that gives to the valley its proper configuration under the new conditions. It therefore blends quite perfectly into the common configuration of the new and old surface formations, and the distinction between the new and the old thus blended in configuration is pre-eminently calculated to escape observation.

The formation does not arise from simple displacement or reworking of any one deposit, but is a *recomposition* of material derived from everything exposed to wash in the portion of the valley undergoing erosion at the time. It may be in itself a consistent formation with definite characters and quite free from signs of post-depositional disturbance. As its material was derived from that which prevails on the upper slope of the same valley, it is very liable to resemble it more or less closely, and this, taken with the harmonious topographic configuration, adds to its liability to be confounded with the original deposit. For example, in a valley whose upper slopes are mantled with loess, with few exposures of older formations, the slope wash is necessarily loess-silt in the main, and the recomposed formation on the lower slope or in the valley must be made up of similar silt merely modified by exposure and transportation. The older formations can only make such contributions to the new deposit as their exposure and erosibility permit, which in the case supposed—a common case—is small. The new aggregation must necessarily bear a close *general* resemblance to the original loess and may easily be mistaken for it.

The criteria for discrimination are found in the effects of partial weathering, in the element contributed by the older formations, and in the structure of the new aggregation, besides the special features which most individual deposits possess as their personal characteristics, so to speak. In a valley whose upper slopes are till or other form of drift, similar recomposition formations of an illusive nature take place.

It should be noted in passing that these are not true alluvial deposits in the typical cases, though they may grade into alluvial deposits and be interstratified with them. They are not habitually well assorted and stratified. They are not formed by persistent streams, but are the products of periodic surface wash and are heterogeneous, unassorted, and, in a sense, structureless, and hence again their liability to be mistaken for one or another of the unassorted drifts.

Among the favoring conditions for such recomposition deposits, there is one which is systematic and recurrent, and is peculiarly adapted to occasion the burial of relics, since it causes a succession of alternate erosions and depositions at localities specially liable to be frequented by primitive man. It is the effect of the meandering of a principal river on erosion and deposition in the mouths of its tributaries.

The meandering of a principal river as a cause of alternate erosion and deposition in the mouths of its tributary valleys. — A meandering river with a deep, readily shifted bottom-filling of the glacial type imposes upon its tributary valleys alternate stages of excavation and filling. These result (1) from the action of the aggressive bends of the river loops against the mouths of the tributaries, and (2) the replacement of these, after a time, by the flood-plain peninsulas that lie within the loops. More specifically, it is the alternate cutting of the stream itself, working hard against and under the mouth of the tributary valley, followed by the building up of the river's higher flood-plain across the mouth of the valley. The first causes the waters of the adjusted tributary to erode; the second, to make deposits in the mouth of the tributary; for in the first stage the axis of the tributary opens out on the river itself, which may be twenty or thirty feet or more lower than the upper flood-plain, and hence the tributary then has its lowest and best opportunity to discharge its waters and their detrital burden. Besides this, the river itself, while in this aggressive attitude, sweeps into the mouth of the tributary in its flood stages and aids in its excavation, and the rushing by of the river's strong current drags out by friction, on the principle of draft, the waters of the tribu-

tary and, by acceleration, aids their excavating action. It is at this stage pre-eminently that the tributaries cut down their valleys into adjustment with the main stream bed. On the other hand, when the active impinging bend of the river has shifted elsewhere, and in its stead a flood-plain is being built up across the mouth of the tributary, the drainage of the latter is checked, and if the tributary be small and its waters incompetent in comparison with the flood-plain aggradation of the river, the valley mouth will be filled to a height corresponding to that of the highest flood-plain.

Further, if the mouth of the tributary be blocked by the upper flood-plain beyond the time of the latter's growth, the wash from the tributary will build a delta or fan upon it, and this further growth will continue until the waters from the tributary valley have built up a suitable gradient for themselves across the flood-plain to the river. This only holds good in valleys of incompetent drainage which cannot cut and maintain a trench for themselves. If the tributary valley has a large competent stream, it will maintain a channel-way across the flood-plain to the river, and less aggradation will result from the shifting of the meanders.

A series of aggradation deposits of the recomposition type are to be looked for on the lower slopes and in the mouths of all tributary valleys, caused by the shifting action of the primary stream, and these may reach depths of twenty or thirty feet, and theoretically much more. As these deposits are subject to geologically rapid construction and removal, they are peculiarly well adapted to bury whatever may occupy the surface in the erosion stage. But such burial must be referred to the date of the recomposition and aggregation of the material, and not to that of the chief parent formation.

Beside this systematic, constantly recurrent case there may be others assignable to the causes named and to more special agencies.

Palæontological criteria.—The previous discussion has been confined to formations within the glaciated area, or immediately connected therewith. Formations not physically connected with

the glacial deposits cannot usually be correlated with the glacial stages so definitely by stratigraphic or other physical means as to furnish unquestionable evidence of their glacial age. In special cases it may be possible, but these cannot well be treated here. The question is, however, pertinent whether palæontological evidence cannot bring these outlying non-glacial deposits into sure correlation, as it does in other parts of the geological column. It is certainly to be presumed that palæontology can do for the Pleistocene period what it has done for earlier ages, but the real question is whether this meets the minute requirements of the question in hand. Has palæontology at any stage reached a degree of refinement that enables it to discriminate surely between stages of the order of the glacial epochs *by the use of criteria developed in other regions than those immediately concerned?* It will not be questioned that when the faunas and floras of each of the glacial stages in America have been well worked out and demonstrably connected with those stages, and when it is shown by ample evidence that certain species lived in America in certain stages, *and not in others*, the criteria so determined can be used in confident correlation; *but these criteria must first be demonstrated to be true criteria in their American application.* General inferences as to the rate of evolution or the rate of extinction are not sufficiently refined for the purposes of this case, without such specific local demonstration. General inferences and faunal aspects may be applicable to periods measured by hundreds of thousands or millions of years, and yet be quite too broad to discriminate epochs of a few thousands or even tens of thousands of years. The historical period of eight or ten thousand years gives little basis for confidence in palæontological refinements of this latter order; certainly not until their specific trustworthiness in a given application is demonstrated. Here as everywhere else in the geological column the range and limitation of species must be demonstrated stratigraphically before the occurrence of these species can be used to fix horizons and determine correlations except in a general and tentative way. The palæontology of the American glacial series is yet to be developed in the main. It is known that many species survived

the earlier and more extensive ice invasions, and became extinct either during the later stages or since the glacial period. It is known that some species survived for some appreciable time after the last glacial stage, and yet became extinct before the American historical period, as, notably, the mammoth and mastodon. The fauna of which the mammoth and mastodon were the elephantine types not unlikely bore an aspect measurably different from that of the same region today, and, but for the stratigraphic proof to the contrary, would undoubtedly be regarded as evidence of rather high antiquity, as indeed was the actual case before the recency of this fauna was demonstrated. The association of man's relics with those of extinct animals merely raises the Janus-faced question whether it means the antiquity of man or the recency of extinction of the animals. General considerations and Old World analogies are incompetent to decide this question in America. It must be worked out by specific stratigraphic and correlated evidences of a degree of precision and refinement commensurate with the geologic minuteness of distinctions involved in the problem.

CONCLUSIONS.

The foregoing analysis has not been carried into all the refinements that special cases involve, but it has perhaps been extended far enough to make clear the general fact that the reliable reference of human relics to a glacial age is attended by many possibilities of error, and that these can be avoided only by the exercise of sagacity, guided by experience and controlled by the most diligent circumspection.

Promising grounds.—Two general classes of formations furnish promising grounds for search, so far as their *trustworthiness* is concerned, when critically studied, viz.: (1) the immediate glacial formations, *i. e.*, the till sheets and the moraines; and (2) the interglacial formations.

Unpromising grounds.—Certain other classes of formations are so subject to error, or at least to the suspicion of error, that there is very slight ground of hope that they will furnish incontestible evidence, and hence cases founded on these formations should

be relegated to the category of doubt, unless the special features of the cases themselves give them convincing force. These classes are: (1) the valley trains of gravel, sand, and silt, except where immediately connected with moraines or possessed of special features that demonstrate their strict contemporaneity with an ice invasion; and (2) all secondary or disturbed deposits, and all recomposition deposits.

All deposits connected genetically with river channels, with eroded bottoms or bluffs formed in valley trains of gravel, are *to be entirely excluded from serious consideration.* They not only do not help on the cause of glacial man in America—if one may speak as an advocate—but they hinder it by throwing doubt over the whole evidence with which they are associated.

The important question of man's antiquity in America will, in my judgment, be helped on to solution most effectually by freely relegating to the shelves all doubtful evidence and by turning search toward the sources whence reliable evidence is most likely to be forthcoming, and by giving to that search the highest possible credentials of scientific trustworthiness. A few really good cases standing by themselves in their own good company would be decisive; a thousand weak ones can only leave the question in doubt.

T. C. CHAMBERLIN.

Reviews.

SUMMARIES OF THE LITERATURE OF STRUCTURAL MATERIALS. III.

Edwin C. Eckel.

Armstrong, L. K. *Portland and Natural Cements of the Pacific Northwest.* Mining, Vol. IX, pp. 134–41, 1902.

Description of the materials and plant of the Pacific Portland Cement Co. The plant is located fifty miles from Newport, Wash., and a mixture of clays, shales, and limestone is used. Analyses of materials and product are given.

Baker, I. O. *A Study of Road-Building Gravels.* Engineering News, Vol. XLVIII, pp. 345–8, 1902.

Detailed discussion, by a leading engineering authority, of a fresh subject. The requisites of a road gravel are: (1) the fragments should be so hard and tough as not easily to be ground into dust by the impact of wheels and hoofs; (2) the pebbles should be of different sizes, each in the proper proportion; and (3) there should be intermixed with the coarser particles some material which will cement and bind the whole into a solid mass. These requisites are separately discussed at some length, and eight typical and well-known road gravels are described.

Brown, C. C., *editor.* *Directory of American Cement Industries and Hand-Book for Cement Users.* 2d ed. 8vo, pp. 740. Price, $5. Municipal Engineering Co., Indianapolis, Ind., 1902.

A second (revised and enlarged) edition of this valuable work first published in 1901.

A chapter on cement-testing gives, in addition to the methods adopted by the American Society of Civil Engineers, the recent reports of the Board of Engineer Officers (U. S. A.), on "Testing of Hydraulic Cements," and of the committee on methods of cement analysis appointed by the New York section of the Society of Chemical Industry. In the second chapter, dealing with cement specifications, samples are given of specifications in use by the War and Navy Departments, the New York Central, Pennsylvania, and Philadelphia & Reading railroads, and the public-works departments of several cities. Under the head of uses of cement are given data on the methods and costs of mixing concrete-and-steel construction, cement pipes, concrete blocks, etc. A long chapter on specifications for the use of cement quotes various specifications covering most of the uses to which cement or concrete may be put. Data on which to base estimates on cement work are given in detail. Several typical laboratories for cement-testing are described. The technology of lime and plaster is discussed more briefly. A large number of typical plants, manufacturing Portland, puzzolan, or natural cements, is described.

Following these valuable contributions to the general subject of cements comes the directory proper. This contains lists of American cement manufacturers; cement brands; sales agents; foreign cement manufacturers; dealers in cement; contractors, engineers, and other large users of cement; cement-testing laboratories; manufacturers of cement machinery; manufacturers of lime; plaster plants; and dealers in lime and plaster.

CLARKE, F. W. *Analyses of Rocks, Laboratory of the U. S. Geological Survey, 1880 to 1899.* Bull. 168, U. S. G. S. 8vo, pp. 308, 1900.

Contains many analyses of building stone and other material of economic interest.

COONS, A. T. *The Stone Industry in 1901.* Extract from Mineral Resources U. S. for 1901. 8vo, pp. 67, 1902.

The value of the stone produced in the United States during 1901 is given as $56,615,926. This total includes granite, $14,266,104; trap, $1,710,857; marble, $4,965,699; limestone, $21,747,061; slate, $4,787,525; sandstone, $6,974,199; and bluestone, $1,164,481.

CUMMINGS, URIAH. [*Production of*] *American Rock Cement* [*in the U. S. during 1900*]. Mineral Resources U. S. for 1900. Pp. 745, 746, 1901.

Résumé of the condition of the American natural cement industry during 1900, with statistics of production.

DAVIS, C. A. *A Contribution to the Natural History of Marl.* Journ. Geol., Vol. VIII, pp. 485–97, 1900.

The influence of lower forms of plant life upon the formation of siliceous sinter, calcareous tuffs, etc., in the neighborhood of hot and mineral springs has been discussed by Weed and Cohn. In the present paper the relation of certain low plant forms to the formation of marl is treated in detail, special attention being given to marl deposits of the type commonly found in Michigan.

The Michigan marl (excluding its contained vegetable matter) is, undoubtedly, derived ultimately from glacial clays and disintegrated rock masses. These clays are rich in finely divided limestones, and in rock-forming minerals containing calcium compounds. Percolating waters, carrying carbon dioxide in solution, readily take up the calcium salts, to a certain limit. If the amount of carbon dioxide contained in the water be considerable, part of it will escape whenever the pressure is lowered. This should result in the precipitation of a corresponding part of the calcium carbonate. As the streams of the area under consideration do not deposit marl where they reach the surface, and as the waters of those springs and streams show no milkiness on exposure to ordinary atmospheric pressures and temperatures, it is inferred that no large amount of carbon dioxide is carried, and that there is no approach to the saturation point for calcium bicarbonate in the springs and streams of the Michigan marl region.

Three alternatives are therefore left: (1) the marl was formed under conditions differing from those at present; (2) the amount of dissolved salts is so small that the saturation point is not approached until after the lakes are reached and the slow evaporation and reduction in the amount of dissolved carbon dioxide brings about

deposition of the lime carbonate; or, (3) animal or vegetable agencies, or both, cause the deposition of the marl.

The writer disposes of the first two possibilities, stating that the marl is formed at and below the present water level, even coating pebbles and living shells; and that the outlets of the marl lakes of Michigan are so large that little, if any, concentration occurs in the lakes.

Molluscan and other invertebrate shells, in fragments of recognizable size, do not contribute largely to the deposits of commercial value; and it is improbable that wave action in these lakes has been sufficiently strong to reduce shells to powder or mud. The sole remaining possible cause, then, is plant action; and this the author discusses in detail.

All green plants absorb carbon dioxide and release oxygen. If the calcium salts are in excess in the water, and are held in solution by carbon dioxide, then the more or less complete abstraction of the carbon dioxide from the water near the plant will cause direct precipitation of lime carbonate upon the leaves and stems. If, however, only minute percentages of lime salts are present in the water, the precipitation of lime carbonate is accomplished, not by the abstraction of carbon dioxide, but through the agency of the oxygen released by the plant, according to the following equation:

$$CaH_2(CO_3)_2 + O = H_2O + CO_2 + O + CaCO_3 .$$

Not all plants are equally active agents. The algæ seem to be of the greatest importance in the formation of marl deposits, one group—the *Characae* or Stoneworts—being of particular importance. Professor Davis collected five stems, each about 60 cm long, of a species of *Chara;* these yielded 3.6504 grains of solid matter, the mineral portion of which carried 93.76 per cent. of lime carbonate, 2.93 per cent. of magnesium carbonate; 2.40 per cent. of silica and undetermined, and 0.89 per cent. of oxides of iron and aluminum. *Chara fragilis* seems so be the most active form in the Michigan marl region, but it is probable that close examination will reveal a number of allied species engaged in the same work.

Pebble-like masses of marl, characteristically ellipsoidal in shape and showing both radial and concentric structure, are attributed to the action of another alga, determined to be a species of *Zonotrichia.* Similar, if not identical, material has been described by Murray, who identified the alga as *Schizothrix fasciculata;* but comparison of these materials was not possible.

DAVIS, C. A. *Second Contribution to the Natural History of Marl.* Journ. Geol., Vol. IX, No. 6. September to October, 1901, pp. 491–506.

Continued investigation, along three distinct lines, confirms the writer's opinion that close relationship exists between certain algæ (especially *Chara*) and marl deposition.

A series of careful mechanical analyses of typical marls from various (Michigan) localities was made. In general, it is easily possible to recognize with a simple microscope the particles held by a hundred-mesh sieve as being *Chara* incrustations or *Schizothrix* concretions; and it is therefore evident that a large part of the samples are of demonstrable algal origin.

The milky appearance of certain lakes has been cited as evidence of the probable presence of calcium carbonate, precipitated from the water by loss of carbon dioxide or change of temperature on reaching the lakes. Experiments show, however, that this turbidity is probably caused by the stirring up of marl deposits by wave action.

Tests showed that a large amount of a soluble calcium salt, determined to be calcium succinate, was present in *Chara*, diffused through the cell sap of the plant. The method of formation of this salt is not at present explainable. It seems probable, however, that it accumulates in the cells until it attains a sufficient density to diffuse through the cell walls by osmosis. Outside the cells or in its passage through the walls, it is decomposed directly into the carbonate. This decomposition is effected possibly by oxidation of the succinic acid due to free oxygen given off by the plants, possibly by some substance in the cell walls, or, more probably, by some organic compounds in the water due to bacterial growth in the organic débris at the bottom of the mass of growing *Chara*.

ECKEL, E. C. *The Quarry Industry in Southeastern New York.* Twentieth Report New York State Geologist, pp. r. 141–r. 176, Pls. XLII–LXI, map, 1902.

Preliminary report on the quarry industry in the counties of New York, Queens, Westchester, Putnam, Dutchess, Rockland, and Orange. Detailed descriptions of formations and quarries are preceded by a summary of the structural and stratigraphic geology of the area.

ECKEL, E. C. *The Utilization of Iron and Steel Slags.* Extract from Mineral Resources U. S. for 1901. 8vo, pp. 17, 1902.

A fairly detailed discussion of the various methods of utilizing slags. In the present connection it is of interest to note that slags are used in the manufacture of Portland and natural cements, slag blocks, slag brick, and glass; and also as road metal and railroad ballast.

This paper was not printed in the completed volume of the *Mineral Resources* for 1901, and is therefore obtainable only in the form above cited.

FISHER, C. A. *Methods of Studying and Displaying Quarry Products as Employed by the University of Nebraska Geological Survey.* Proc. Nebraska Acad. Sci., Vol. VII, pp. 153–5, Pls. XI–XIII, 1901.

Brief description of the methods of gathering data regarding quarries, and of utilizing this information in the display of specimens.

GILLETTE, H. P. *The Cause of Masonry Disintegration.* Engineering News, Vol. XLVIII, pp. 340–42.

Discussion of masonry disintegration in high latitudes; with arguments tending to prove that this disintegration is due primarily, not to frost, but to alternate expansion and contraction attending changes of temperature. The paper cannot well be summarized, but is included here as being closely connected with the subject of the decay of building stone.

KIMBALL, L. L. *The Production of Cement in 1901.* Extract from Mineral Resources U. S. for 1901. 8vo, pp. 17, 1902.

During 1901, fifty-six plants produced 12,711,225 barrels of Portland cement, valued at $12,532,360. Natural cement was manufactured by sixty plants, the product being 7,084,823 barrels, valued at $3,056,278. Five plants are said to have produced 272,689 barrels of slag cement, valued at $198,151.

McCallie, S. W. *Some Notes on the Trap Dikes of Georgia.* American Geologist. Vol. XXVII, pp. 133–4, Pls. XII–XIV, March, 1901.

Notes on the distribution and character of the trap dikes, which are possibly of Triassic age.

Middleton, J. *Statistics of the Clay-Working Industries in the United States in 1901.* Extract from Mineral Resources U. S. for 1901. 8vo, pp. 78, 1902.

The total value of clay products in the United States during 1901 was $110,211,587; the number of firms reporting being 6,421.

Newberry, S. B. *Fuel Consumption in Portland Cement Burning.* Reprinted July, 1901, from Cement and Engineering News. 8 pp.

Discussion of the theoretical and actual fuel requirements of the various types of kilns in use, and of the effects of the different methods of mixing the slurry.

Newberry, S. B. [*Production of*] *Portland Cement* [*in the U. S. during 1900*]. Mineral Resources U. S. for 1900, pp. 737–44, 1901.

Résumé of condition of American Portland cement industry during 1900, with statistics of production. A discussion of fuel consumption is given, abstracted from the previous paper.

Parsons, A. L. *Recent Developments in the Gypsum Industry in New York State.* Twentieth Rep. N. Y. State Geologist, pp. r. 177–r. 183.

Descriptions of the gypsum deposits at Fayetteville, Union Springs, Marcellus, Mumford, and Oakfield; with notes on the technology of calcined plaster — the manufacture of which has recently become an established industry in the state.

Ries, H. *Occurrence of Glass-Pot Clays in the United States.* Extract from Mineral Resources U. S. for 1901. 8vo, pp. 17, 1900.

Glass-pot clays should be highly refractory, very plastic; dense burning, low in flexing constituents and silica, and high in tensile strength. These requisites are briefly discussed, and certain typical foreign pot-clays are described in detail. American pot-clays are derived from the Carboniferous of Pennsylvania and Missouri, occurring in close association with other refractory clays. Analyses and tests of a number of these domestic materials are given.

Ries, H. *The Production of Flint and Feldspar in 1901.* Extract from Mineral Resources U. S. for 1901. 8vo, pp. 9, 1902.

A quantity of 34,420 short tons of "flint" (quartz), valued at $149,297, was produced in the United States during 1901. This was mined in Maine, Massachusetts, Connecticut, New York, Pennsylvania, Maryland, and Wisconsin; and is largely utilized in potteries and in the manufacture of wood-fillers and scouring-soaps.

Feldspar was produced in Maine, Connecticut, New York, Pennsylvania, and Maryland, the total amount being 37,741 short tons, valued at $220,422. It is used in the manufacture of pottery, wood-fillers, scouring-soaps, and glass.

Russell, I. C. *The Portland Cement Industry in Michigan.* Twenty-second Ann. Rep. U. S. G. S., Part III, pp. 629–85.

Brief notes on the history of the Portland cement industry in Michigan and the general technology of Portland cement are followed by detailed discussions of the

limestones, marls, shales, clays, gypsum, and fuel supplies of Michigan, in connection with the cement industry. Following these are notes on factories, processes, product, etc. The sections on materials will be summarized.

Limestones from two formations (Dundee and Traverse) have been used in making Portland cement, while other limestones may be so utilized in the future. The Dundee limestone occurs at the base of the Devonian, and contains at least one bed of sufficient purity to be used in Portland manufacture. Material from this bed is utilized by the Michigan Alkali Co. at Wyandotte. The limestones of the Traverse group (Devonian) are used in the manufacture of Portland cement at Alpena.

Certain Silurian limestones may furnish a natural cement, while Eo-Carboniferous limestones, not at present used in Portland cement manufacture, are sufficiently low in magnesia to be a possible future source of Portland material.

Marl deposits of great area and depth occur abundantly on the lower peninsula of Michigan. A map of this portion of the state showing the location of the best-known deposits and of actual and proposed Portland cement plants, is presented. Numerous analyses of Michigan marls are given, and their physical properties, chemical composition, and probable origin are discussed in detail; the conclusions of Davis as to origin being restated and carefully considered.

Shaes of the Traverse (Devonian) and Coldwater (Carboniferous) formations are used in Portland cement manufacture; the former at Alpena, the latter at Union City and Coldwater. The Antrim shales of the Devonian and the Saginaw shales of the Carboniferous, are referred to as of possible use.

The surface clays are, in general, too sandy to be of use in cement manufacture, though they have been so used at Wyandotte. Several Michigan cement plants obtain their clay from Ohio.

Most of the gypsum used in the Michigan cement plants is procured from the extensive deposits near Grand Rapids.

The coal used is mostly from Ohio and Pennsylvania, though Saginaw Valley coal has been used to a small extent.

During the year 1900 five Portland cement factories were in operation in Michigan, while several others were in course of construction. Of those in operation, four were equipped with rotary and one with dome kilns. As regards materials, two plants used marl and clay; two, marl and shale; while one plant used precipitated lime carbonate (caustic soda waste) and clay. Only one of the plants in construction is designed to use limestone and shale; the others using marl with clay or shale.

STRUTHERS, J. *The Production of Gypsum in 1901.* Extract from Mineral Resources U. S. for 1901. 8vo, pp. 13, 1902.

An amount of 659,659 short tons of gypsum, valued at $1,577,493, was produced in the United States during 1901. Of this amount, 521,292 tons were calcined, the remainder being largely used as land plaster.

TAFF, J. A. *Chalk of Southwestern Arkansas;* with Notes on its Adaptability to the Manufacture of Hydraulic Cements. Twenty-second Ann. Rep. U. S. G. S., Part III, pp. 687–742, Pls. XLVII–LIII, Figs. 57–69, 1902.

Descriptions of the general geography and geology of the region are followed by a detailed discussion of the two chalk-bearing formations, with local details of the

available deposits. Following this is a summary of the technology of Portland cement; notes on the chalks (Taff) and clays (Branner) of southwest Arkansas as Portland cement materials; and a brief description of the Whitecliffs cement plant. The subjects are well arranged; and the section on cement technology is rather more satisfactory than the material usually offered under this heading.

The sandy basal member of the Upper Cretaceous, prominent in Texas and Indian Territory, is concealed throughout its extent in Arkansas by post-Cretaceous gravels and sands. The lowest member of the Upper Cretaceous visible in Arkansas is therefore the marl overlying this basal sandy member. This marl is a continuous formation, and increases gradually in thickness from 30 feet at Austin, Tex., to 300 feet at Whitecliffs, Ark. Overlying this marl is the Whitecliffs chalk, which in turn is overlain by 200 feet of blue limy marl. Above this is the Saratoga chalk, which is succeeded by greensands and clay marls. The Whitecliffs and Saratoga formations will now be discussed in some detail, as being possible sources of Portland cement materials.

The Whitecliffs chalk is exposed, in Arkansas, in three separate areas, being covered in the intervening regions by post-Cretaceous deposits. These areas are in the vicinity of Rocky Comfort, Whitecliffs, and Saline Landing. In the Rocky Comfort area the thickness of the formation could not be precisely determined, but probably exceeds 100 feet. Farther east, at Whitecliffs, nearly 100 feet of chalk is exposed, and the top of the formation is concealed. Still farther east, at Saline Landing, less than half this thickness is shown. At Okolona no chalk occurs, its stratigraphic position being occupied by a chalky marl. The Whitecliffs chalk therefore occurs as a wedge, thickest toward the west, and coming to an end near the middle of the Cretaceous region of southwest Arkansas.

The Saratoga chalk formation occurs 200 feet above the Whitecliffs formation, and separated from the latter by marls. The maximum thickness of the Saratoga chalk is 30 feet; it is exposed in three areas in Arkansas, located respectively at Washington, Okolona, and Deciper.

Analyses show that these chalks of both formations vary greatly in composition; the lime carbonate varying from 49.90 per cent. to 90.01 per cent.; the silica and insolubles, from 4.91 per cent. to 43.72 per cent. In one respect the specimens agree: they are all sufficiently low in magnesia to come well within Portland requirements.

WILDER, F. A. *Present and Future of the American Gypsum Industry.* Eng. & Min. Jour., Vol. LXXIV, pp. 276–8, 4 Figs., 1902.

Brief review of the origin and distribution, both geographical and geological, of gypsum deposits; followed by a somewhat more detailed discussion of the uses of gypsum and the methods of manufacture of the various gypsum products, with interesting notes on recent German practice in the manufacture of plasters.

Origin of the Oligocene and Miocene Deposits of the Great Plains.—By J. B. HATCHER. (Proc. Am. Phil. Soc., Vol. XLI. [April, 1902].)

AFTER an introductory statement regarding the various horizons of the Tertiary deposits of the western plains, the author proceeds to a

consideration of their origin. He shows that up to the present time the lacustrine theory has been generally accepted, but that recently the difficulties of that theory have been pointed out. The lacustrine origin of the Upper or Loup Fork formation has been rejected by many observers, and now it is generally considered to be as of combined lacustrine, fluviatile, flood-plain, and æolian origin. The lower division or White River beds are still regarded by many to be of lacustrine origin. To these deposits the author turns his attention.

The lacustrine origin of the White River beds was called seriously in question in 1899 by Dr. W. D. Mathew, of the American Museum of Natural History. W. D. Johnson, also, in the *Twenty-first Annual Report of the United States Geological Survey*, regards all of the Tertiary deposits of the plains as of fluviatile and flood-plain origin. Mr. Hatcher draws from his wide experience in these beds and presents facts which seem overwhelmingly conclusive in favor of their fluviatile origin as opposed to their lacustrine origin. The physical and palæontological evidences combine to fortify his position. The invertibrate remains were examined by Dall, Pilsbey, and Stanton, who agree that "they belong to species inhabitating swamps and small ponds." Dr. Knowlton reports that the plants are those of "springs, shallow ponds, and brooks," while the author shows that the evidence derived from the vertebrate remains indicates that the lacustrine hypothesis is untenable.

Mr. Hatcher does not rest with an attempt at destroying the old hypothesis, but presents in its place a rational explanation which satisfactorily accounts for the observed phenomena. He still further strengthens his position by quoting from Mr. H. H. Smith, who describes a region in South America which presents, at the present time, conditions similar to those postulated for the accumulation of the White River deposits. This region exhibits a somewhat remarkable condition of meandering and interlacing streams over a low-lying tract of country which is annually submerged by the floods. The region is comparable in size to the Tertiary deposits discussed, and gives a picture of the possible conditions of our western plains during Oligocene and Miocene times. Seldom do we find an article more replete with valuable and interesting observations. It would seem that those who still entertain a strict lacustrine hypothesis in explanation of the White River deposits would do well to strengthen their position in some more substantial manner than has hitherto been done.

WILLIS T. LEE.

AUTHOR'S ABSTRACTS.

THE GEOLOGICAL SOCIETY OF AMERICA, CORDILLERAN SECTION.

FOURTH ANNUAL MEETING.

THE fourth annual meeting of the Cordilleran Section of the Geological Society of America, was held partly in the rooms of the Academy of Sciences, San Francisco, and partly in the rooms of the Department of Geology of the University of California, Berkeley, December 30 and 31, 1902. The officers elected for the ensuing year were H. W. Fairbanks, chairman; Andrew C. Lawson, secretary; and W. C. Knight, councilor. The following papers were read and discussed:

The Synthesis of Chalcocite and its Genesis at Butte, Mont. By HORACE V. WINCHELL, Butte, Mont.

IT was stated that chalcocite is the principal ore of copper at Butte, and that it is one of the latest minerals to be formed in the veins. It is believed that the mineral was formed by a chemical reaction between copper sulphate in solution in descending waters and the iron pyrites and other sulphides below. Some synthetical experiments were described to prove this. The active agent in the reduction of the copper salt to the cuprous state seems to have been sulphurous anhydride, SO_2, as the experiments showed that when pyrite was digested in a solution of copper sulphate containing SO_2, it became coated with a layer of chalcocite, while in the same solution without the SO_2 the pyrite remained just as bright and yellow as before immersion.

A Geological Reconnaissance of the Region of the Upper Main Walker River, Nevada. By D. T. SMITH, Yerington, Nev., presented by Andrew C. Lawson.

THIS region is in the western part of the state of Nevada, between latitudes 38° 50′ and 39° 10′. It comprises the greater portion of a valley of general north–south trend. Nearly ten miles of the eastern range and sixteen of the western have been mapped geologically.

The eastern range is made up of granitic rocks—andesite, rhyolite, and limestone. The western range is also made up of these, together with basalt, schists, garnetiferous rocks, and intrusives. In both ranges are some later Tertiary strata. The metamorphics are

nearly transverse to the axis of the valley. In them are deposits of copper ore, and directly across the valley and having the same trend as the metamorphics are copper-bearing veins in the granitic rocks.

In several instances the genesis of the deposits has been ascertained. This came out through a study of the deposits and the country rock. In some places sufficient mining has been done to give helpful exposures of the deposits in depth.

The relation of the country rock, bearing the deposits, to the other rocks of the region was discussed in detail. Structural features, both general and local, were given special attention. It was hoped to correlate events with some other well-known part of the Sierras, but this was not entirely possible. No fossils from the limestone were found, nor have any been reported, so far as could be learned. The limestone however, is much plicated and petrographically borders closely on to marble. This would seem to suggest a relationship with that of the Sierra Nevada. The Tertiary strata are made up of material of all the rocks above mentioned, except the basalt, and perhaps an andesite, which seems to occur later than the ryolite, and is different from the andesite above mentioned. In the strata were found Pliocene vertebrates and a few triassic shells — presumably from the limestone.

The Correlation of the John Day and the Mascall. By JOHN C. MERRIAM and WM. J. SINCLAIR.

THE age of the John Day is commonly given in geological textbooks as Middle Miocene. A study of the large collection of vertebrate fossils from these beds made by the University of California, leads to a different view of the age of this formation.

The state of evolution of this fauna is practically identical with that of the Upper White River. Several genera occur in the Middle John Day which are found for the first time in the Protoceras beds. Associated with these are such persistent types as *Elotherium* and *Mesohippus*, which range far back into the Lower White River. But that the Middle John Day is not older than the Oreodon beds is shown by the total absence of Creodonts and Titanotheres, while it differs from the Oreodon beds in containing later introduced types, which are not known to range farther back than the Protoceras beds.

The Upper John Day contains several genera which have not been found in the Middle John Day (*Protomeryx*, *Protapirus*, *Promerycochærus*). These seem to have entered Oregon as migrants from some

of the eastern basins of accumulation. There are no related forms in the Middle John Day. With the exception of *Promerycochœrus*, and possibly some of the Rhinoceroses which have not yet been fully worked up, all the ungulate genera of the John Day are the same as those of the White River.

The Upper John Day has its closest affinities with the Middle John Day, and is probably in greater part Upper Oligocene, although it may overlap on the Lower Miocene. The Middle John Day is to be correlated with the Protoceus horizon of the White River Oligocene. The lower limit of the Upper John Day is determined by the downward range of *Promerycochœrus* in the beds.

This genus, which also occurs in the Mascall, and *Mylagaulodon angulatus*, gen. and sp. nv., and later types unite in a measure the gap between the Upper John Day and the Mascall faunas.

The presence of *Desmatippus crenidens* in the Mascall serves to correlate this formation with the Deep River beds. The flora preserved in the lower levels of the Mascall formation determines its age very definitely as Upper Miocene.

The Columbia lava represents in the stratigraphic series an erosion interval between the Upper White River and the Loup Fork in the plains region.

The Valley of Southern California. By E. W. Hilgard, Berkeley, Calif.

This paper treats of the orographic relations and post-Tertiary formations of the valley region extending from Los Angeles to Redlands, showing it to have been a topographic unit anterior to the subdivision of the drainage into the San Gabriel and Santa Ana systems by the extraordinary development of débris fans which now form the sources of artesian waters.

The Potter Creek Quaternary Bone Case. By Wm. J. Sinclair; presented by J. C. Merriam.

The case, which is situated near Baird, Shasta county, Calif., contains a thick deposit of alternating layers of clay, case breccia, and stalagmite resting in part on a stratum of volcanic ash. The ash reposes, either directly or with the intervention of some clay, on a floor of cemented case breccia known to be in part about a foot and a

half thick. Excavation has not yet been prosecuted beneath this floor. The volcanic material is composed of fine fragments of glass.

Bones, in an excellent state of preservation, recur in all the deposits except the ash. They represent an *Equus* fauna of plains and forest type combined, much richer in species than any Quaternary fauna known from this coast. Among the larger forms represented are *Elephas*, *Mastodon*, *Megalonyx?*, *Rhinoceros*, *Equus*, and *Arctotherium*. Many smaller carnivora are present, many of them of extinct species. Among the rodents there is a new rabbit, a new squirrel, a new *Teanoma*, etc. Two species of deer are represented by numerous specimens.

At the time of the accumulation of the case deposit, the topography of the adjacent region had not assumed its present rugged character. The case was formed by percolating waters during the cutting of the McCloud river canyon. Infilling does not seem to have been contemporaneous with the excavation of the case. It is possible that much of the accumulation in the case antedates the Red Bluff epoch.

Further study will be required before the exact position of this fauna in the Quaternary case can be stated.

The Physiography of Southern Arizona and New Mexico. By H. W. Fairbanks.

The great plain-like valleys of southern Arizona and New Mexico are extremely interesting. They stretch eastward from Yuma, where they are but slightly elevated above the sea, toward the continental divide, where they attain an elevation of 5,000 feet. From this point they gradually descend to 4,000 feet at El Paso, and are known to reach still farther eastward toward the Gulf of Mexico.

The plains are dotted with mountain ranges, which in southwestern Arizona are completely isolated and rise very abruptly, but toward the east the mountains break up the plain to such an extent as to form nearly inclosed basins.

A discussion of the origin of the nearly level surfaces of the broad valleys of the southern portion of the Great Basin and those adjacent to the lower Colorado led to the conclusion that three distinct types are to be distinguished: (1) those produced by erosion, as in the Mohave desert north of Kramer; (2) those of stream accumulation in old valleys, formed by the coalescing of débris fans; (3) those of accumulation in bodies of water.

The delta accumulations of a large stream like the Colorado are very different in nature of material and manner of arrangement from those constituting the waste slopes or débris fans; and besides, at the time the great valleys of Arizona were filled to their present level there is no reason to suppose that there was such a river as the Colorado in this region.

As a result of the attempt to discriminate the origin of the nearly level surfaces of the plain-like valleys of the Southwest, the conclusion was reached that those of southern Arizona, as typically represented in the region about Tucson, are the result of accumulation under a body of water, and that this water could have been none other than the northern and eastern extension of the Gulf of California. At Tucson the plain has an elevation of about 2,200 feet.

Professor Blake has described the extension of the beds of this plain into southeastern Arizona, where in the San Pedro valley they attain an elevation of 4,000 feet. In the lower end of the valley he has found beds of diatomaceous earth which are thought to be of marine origin.

The floors of these plain-like valleys appear dissected as they rise toward the continental divide, and upon the middle Gila river are exposed in cliffs several hundred feet high and capped by flows of basalt. Basalt also forms a portion of the floor of the plain between Yuma and Tucson. The beds appear nowhere to have undergone other disturbance than simple uplift. Their materials are but slightly consolidated, and the writer believes with Professor Blake that they probably belong in the late Tertiary or early Pleistocene.

Valleys filled with similar well-stratified material extend across the continental divide, but their surfaces are in places modified by débris fans and in others dissected by erosion.

At El Paso well-stratified beds of fine detrital material have been cut through by the Rio Grande. There can be no question about their belonging with those farther west. They extend many miles east of the city, but just how far the writer does not know from personal observation. The presumption is that they reach the Gulf of Mexico.

From the facts presented it is legitimate to draw the conclusion that during the late Tertiary the whole of the southwestern portion of the United States as well as northern Mexico was very much lower than now, and that the sea reached in through long arms among the mountains toward the present continental divide. Just how far it is impossible to say from present knowledge, but the facts point toward

the presence of bodies of water in all the large plain-like valleys in the region of the present continental divide in the latitude of the Mexican border. They may have been more or less isolated by the low divides connecting the mountain ranges, but were probably at or near sea level.

During the deposition of the beds and following them flows of lava occurred in places, and then the uplift and arching of the crust along the present divide.

This differential uplift gave rise to the conditions necessary for the excavation of the great canyons of the Plateau region and perhaps originated the Colorado river. The lower portion of this stream as well as the Mohave river has been superimposed upon an old topography as shown at numerous points.

Some Gypsum Deposits of Northwestern Nevada. By GEO. D. LOUDERBOCK, Reno, Nev.

A DEPOSIT of gypsum occurs some six or seven miles south of Virginia City. It is an isolated mass inclosed in limestone walls, the whole surrounded, in the main, by diorite. The principal body gives a surface exposure of over 100 yards in width and over 150 yards in length. This is practically all gypsum almost vertical in attitude. The mineral occurs as a milk-white holocrystalline granular aggregate, with some soft secondary earthy material at the surface and along a gully draining the area. The granular variety is quite pure, running generally over 90 per cent. $CaSO_4.2H_2O$, the chief impurity being $CaCO_3$.

Another large deposit occurs in the Humboldt range some five miles east of Lovelock. It occurs interstratified with limestone and a little quartzite. While undisturbed by intrusion, it is faulted and folded. Surface exposures of 300 yards or more in width occur, some two-thirds of which is gypsum, the rest mainly limestone. The thickest gypsum bed is about 150–175 feet thick. The mineral occurs as a holocrystalline granular aggregate except on the surface and lower slopes down which it has washed. It runs from 95–97 per cent. $CaSO_4.2H_2O$, practically the only impurity being calcite.

Reasons are given for believing that both of these gypsum deposits are original members of the stratigraphic series—*i. e.*, that they were formed by deposition from a saline water-body, and are probably of Middle or Upper Triassic age.

Physiography and Geology of the Siskiyou range. By F. M Anderson.

The Siskiyou range forms the central portion of the mountain system often referred to as the Klamath mountains. It follows approximately the boundary line between Oregon and California, and, branching toward the west, divides the drainage of the region in three directions, on the north toward Rogue river, on the south toward the Klamath river, and on the west toward Smith river. The topography of the range, together with its main geological features, suggests a system of transverse folds, one of which is older than the other. The areal geology of the range consists of an alternate succession of igneous and sedimentary, or metamorphic, belts crossing the major axis of the range nearly at right angles. The axis of the range is interpreted as being an expression of, or representing, an earlier topography, and the geological zones as representing a later system of folding.

There is a variety of both igneous and sedimentary, or metamorphic, rocks. The igneous rocks range from ultra-basic to acid types, and are mainly deep-seated. Three belts of igneous rocks cross the range. The sedimentary rocks are for the most part Palæozoic in age, though Triassic rocks may also occur. They include radiolarian cherts, siliceous and calcareous slates, limestones, and crystalline schists. The character of the metamorphic rocks varies in accordance with the character of the original sediments and with the character of the plutonic which has effected their metamorphism.

Magmatic differentiation in the plutonic rocks is extreme, the granitic rocks passing by gradations into diorites, gabbros, and other pyroxene-bearing rocks.

The Genesis of Ore Deposits in Boulder County, Col. By Rufus M. Bagg, Jr., Brockton, Mass.

The geology of Boulder county was outlined. The formation of veins was considered. A description was given of the occurrence of fissure veins along irregular fracture zones which, after faulting, have been secondarily filled with solutions and sublimation products, chiefly the tellurides of gold, mercury, and the sulphide of iron, marcasite. The genesis of these rich ore pockets was discussed. A description of some of the principal mines was given. A summary of field observations when examining mines in the district was given.

A Contribution to the Geology of the Leucite Hills, Wyoming. By J. F. KEMP, New York, and W. C. KNIGHT, Laramie, Wyo.

The Mechanics of Igneous Intrusion. By R. A. DALY, Ottawa, Canada.

THE more important facts of the writer's summary are:

1. *The facts of the field.*—(*a*) Lack of sympathy between structural planes in the invaded formation and form of intrusive body. (*b*) Respective magmatic chambers are not prepared for intrusion by circumferential faulting. (*c*) Contact phenomena demonstrate some kind of active assimilation of their corresponding country rocks by the respective magmas. (*d*) In the normal stock there is a lack of any enrichment of the endomorphic zone by the invaded formation; general freedom in the interior and characteristic abundance of angular inclosures near the contacts; exceedingly sharp lines of contact with country rock; a high degree of homogeneity in the igneous body, and common occurrence of many long and narrow apophyses form the igneous body. (*e*) Isolated observations prove that solid rocks may sink in molten magmas because of differential density.

2. *The facts of experimental research.*—The experiments of Barus, Doelter, Daubree, Cossa, Bischof, Cotling, Morozewicz and others show: (*a*) that representative natural or artificial silicate mixtures, at ordinary atmospheric pressure, become thinly molten at a temperature only slightly above that of solidification; (*b*) that, in every instance, a great increase of volume characterizes the change from the solid to the liquid state; (*c*) that, with strong probability, the volume increment and resulting density decrement are so far preserved in rock magmas under plutonic conditions as to forbid the flotation of blocks of the average country rock immersed in the average magma in depth; (*d*) that the chief rock-forming minerals are soluble in all of the melted silicate mixtures yet investigated and at the temperature ruling when those mixtures are thinly molten; (*e*) that rock magmas become thinly molten at temperatures very slightly above the melting point.

3. *The tests of the hypotheses of overhead stoping and enlargement of magma chambers.*—Reasons are given for concluding that the cause cited for overhead stoping is quantitatively sufficient for the majority of stocks and "batholiths," and the detailed phenomena associated with these inclusions are facts of nature expected on the hypothesis.

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Finally the author concludes that "dikes, sheets, laccoliths, 'byamaliths,' and perhaps a few of the smaller stock-like plutonic bodies are conceived to be due to crustal displacement permitting intrusion; that marginal assimilation in the preparation of subterranean magma chambers is quite subordinate to magmatic overhead stoping; and that *abyssal* assimilation, in contrast to marginal (*hypabyssal*), is responsible for the preparation or notable modifications of magmas whence come, through differentiation, the igneous rocks of the globe."

A Structural Section of a Basin Range. By GEORGE D. LOUDERBOCK, Reno, Nevada.

THE prevalent idea of the structure of the "Basin ranges" having been called into question, a structural section of the Humboldt Lake Range and adjoining country is presented as a contribution to the discussion. This range, where studied, is shown to be made up of strata of the Triassic and Jurassic periods, faulted, folded, in places overturned, which were greatly eroded, in fact were practically in a peneplained condition, before the outpouring of the Cenozoic volcanics. Over their upturned and eroded edges lies a volcanic series made up of rhyolites, rhyolite tuffs — some being current bedded, and with conglomerate layers — capped by basalt. This series is faulted and tilted in a simple manner, in great contrast to the older rocks. Reasons are given for believing that these volcanics were laid down at an approximately horizontal attitude, and that the volcanics of the range and those of the valleys on either side were continuous. On the east slope of the range, the series passes from the summit to the base, with some 20° dip, and disappears under the detritus of the valley. On the west slope they are not to be found, but they occur at the west base, butting into the range at an approximately horizontal attitude, indicating a fault on the west side and simple tilting of the range as a comparatively rigid block.

A well-checked use of the volcanic rocks, which are so abundant in the Great Basin region, to determine the character and extent of the more recent earth movements is urged, and examples are given from other ranges where it has proved of value.

The structure of the range may also be arrived at by the application of the physiographic criteria so concisely stated by Davis;[1] for (1) the range has a unity, and a consistent front, and while lying between broad flat valleys, it shows no approximation to broad intermontane

valleys; and (2) the form of the range does not agree with the structure of its bed rock series, which latter is variously folded and tilted, in ways not expressed by the physiography, and shows varying degrees of obliquity to the front of the range.

The great erosion of the fault scarp, and lack of erosion of the basalt at its base, shows that the valleys have, during the history of the range as a faulted block, been anything but seats of great erosion; and the great thickness of alluvium and lake deposits shows that they have been areas of deposition.

The following papers for lack of time were read by title:

The Probable Cause of Water Flow in the Mines of Cripple Creek, Colo. By RUFUS M. BAGG, JR., Brockton, Mass.

The Paddles of Shastasaurus. By JOHN C. MERRIAM, Berkeley, Calif.

The Quaternary of the Middle Coast Ranges of California. By ANDREW C. LAWSON, Berkeley, Calif.

ANDREW C. LAWSON,
Secretary.

AUTHORS' ABSTRACTS OF PAPERS READ AT THE WASHINGTON MEETING OF THE GEOLOGICAL SOCIETY OF AMERICA.

Direction of Flow of the Ancient Beaver River, Shown by Pot-holes. By RICHARD R. HICE.

THE evidence of the slope of the remaining fragments of abandoned fluvial plains may not always be conclusive as to the direction of flow of the stream that formerly flowed over them. Pot-holes, one of the features of stream erosion, are conclusive. On the Beaver River from Beaver Falls to below the Fallston dam, the present channel, cut in the Homewood Sandstone, is marked by typical pot-hole erosion. Views of pot-holes below the Fallston dam show in all cases that the up-stream side of the hole is abrupt, and often undercut, while the down-stream side is rounded off and eroded by the action of the flowing water. This also applies to channels formed by

[1] *Science*, September, 1901, p. 457.

pot-holes cutting into one another. Near Rock Point the abandoned bed of the old stream, 150 feet above the present stream, is also in the Homewood Sandstone. A number of pot-holes have been seen here, and views show that the steep side is on the southern side, and the eroded, rounded side on the northern side of the hole, thus clearly indicating that the former stream flowed northward.

The fragments of the bed of this old north-flowing Beaver are practically level from Pittsburg to Rock Point, a distance of about forty miles. The next fragments found a few miles north of these pot-holes are, however, some 80–100 feet lower than at the pot-holes. Observation shows that pot-holes are formed only where the stream is very rapid, and these pot-holes, therefore, indicate that the old north-flowing stream had a greatly increased fall northward for several miles, and a series of rapids here occurred, or perhaps a fall. The pot-holes, therefore, bring the fragments farther north (810 feet) into harmony with the level at the pot-holes (900 feet), and harmonize the almost horizontal fragments southward to Pittsburg, with the 80–100 feet of fall found immediately northward.

Ames Knob, North Haven, Maine; A Seaside Note. By BAILEY WILLIS, Washington, D. C. (Abstract of Paper to Appear with Illustrations in *Bull. G. S. A.*)

AMES KNOB is a mass of andesitic volcanic rock rising 160 feet above the sea, on the neck of land between the Fox Island thoroughfare and South Harbor, North Haven Island, in Penobscot Bay. Its petrographic character and geologic relations have been described by G. O. Smith, in his essay on the geology of the Fox Islands, Me. It is bounded on the north by a low plain cut in shales and limestones, of Niagara age, and its northern slope is a cliff resulting from the relatively great hardness of the igneous rock. The other slopes of the knob are of practically uniformly resistant rock, and variations in profile are attributable to conditions of attack, rather than of resistance. At an altitude of approximately 80 feet above the sea, on the southeastern and southern sides facing the Atlantic ocean, is a well-marked bench from which a steep facet rises 40 to 60 feet to the summit of the knob. This bench, which has an average width of about 200 yards, is attributed to the action of waves cutting at rock level. The rocks in place exposed upon this bench and about its margin exhibit rounded glaciated profiles, but no longer bear striæ, so far as observed. Hence

it is inferred that the date of submergence to this level preceded and continued to the latest episode of glaciation, and that later influences have removed the minor evidences of ice action. Upon this glaciated bench there are now deposits of glacial gravel having the characteristic forms of spits and bars, which are accordingly attributed to wave and shore currents. These deposits indicate the presence of the sea at this level after the retreat of the ice.

The simplest explanation of the facts is that Ames Knob was submerged beneath the sea to a depth of 80 feet above the present sea level before, during, and immediately after the latest glacial episode.

Permian Elements in the Dunkard Flora. By DAVID WHITE.

THE Dunkard series (Upper Barren Measures, XVI) comprises the topmost Paleozoic sediments in the Appalachian trough. It occupies a considerable area in southwestern Pennsylvania, northern West Virginia, and eastern Ohio, and the total thickness in northern West Virginia is probably over 1,200 feet. In the absence of marine organisms, the determination of the age of the beds rests on the fossil floras, the only important palæontological evidence at present available.

Extensive plant collections made at several localities were fully described in 1880 by Professors William M. Fontaine and I. C. White, who from their study of the flora and the lithology concluded that the entire series was Permian. This conclusion has been questioned by some American geologists and palæobotanists on account of the large proportion of Coal-measures types, the paucity of genera and species characteristic of the Permian of Europe, and the similarity as well as continuity in the sedimentation.

Additional material recently collected materially increases the number of identical characteristic Permian species, which now includes three species of *Callipteris*, in or above the Washington limestone, while the examination of the types in other genera emphasize the Permian aspect of a number of other forms. The data now available leave little room for doubt that the upper part, of the Dunkard at least is Permian, the stratigraphical occurrence of the species rendering it probable that the beds down to and including the Washington Limestone, about 175 feet above the base of the series, may with safety be referred to that period. The evidence as to the age of the lower beds of the series is, in the judgment of the writer, not yet suffi-

ciently complete to be satisfactory or conclusive. On account of the continuity in sedimentation, with little epeirogenic movement and but slight lithological differences as compared with the preceding formations, and on account of the presence of a transitional flora including many persistent Upper Coal-measures species, a much more thorough investigation of the plant fossils of the Dunkard and Monongahela measures will be necessary before the boundary or approximate limit between the Coal-measures and the Permian can be drawn.

Walchia and *Ullmannia*, though present in other Permian basins of this continent, have not yet been found in the Appalachian trough. The upper part of the Dunkard is referable to the Rothliegende, probably to the Lower Rothliegende. Beds of the Zechstein or Upper Permian do not appear to have survived in the Appalachian basins.

Glacial Bowlders Along the Osage River. By E. R. Buckley, S. H. Ball, and A. T. Smith.

The discovery of glacial bowlders along the Osage river, fully thirty miles south of the known southern limit of the ice sheet, was simply an "episode" in the systematic strategraphic work which the Missouri Bureau of Geology and Mines is at present conducting in the Ozark region. The fact, however, that in no less than eight localities along the Osage river in Miller county granitic bowlders of undoubted foreign origin were observed is in itself a contribution to the glaciology of this region. This discovery also has a bearing on the physiographic history of the region, giving evidence of the age of the Osage river channel.

In brief it may be said that, if one were to include foreign erratics of all sizes observed at the eight localities, he might perhaps account for several hundred bowlders. These bowlders consist of several varieties of granite, granite-gneiss, and diorite. They range in size from pebbles having a diameter of several inches to bowlders three feet in diameter.

They occur along the present river channel and also back from it, along the tributary streams. In no case, however, were they found at a greater elevation than 605 feet A. T., which in that region is about 70 feet above the low-water level of the Osage river. Nowhere on the ridge land between the Osage and Missouri rivers is there any evidence of glaciation.

The evidence at hand warrants us in believing that the glaciers did

not override the ridge land to the north and that the bowlders above referred to do not indicate the former extension of the ice sheet to that point. Although it has lately been pointed out that the ice sheet extended beyond the head waters of the Osage river in Kansas, it is thought very improbable that these bowlders could have been carried that distance on ice floes. The more reasonable explanation of their present location is through icebergs or floating ice carried from the Missouri river on back-water caused by an ice-jam below the mouth of the Osage. This is the present accepted explanation of their origin. Other explanations, such as changes in the course of the river, have not proved tenable.

Accepting the above explanation of the source of the bowlders, it leads to the important conclusion that the channel of the Osage river was, in part at least, defined prior to the glacial period. The history of the Osage river, with its meandering course as it flows between steep cliffs on either side, has presented to the geologists of Missouri a very interesting problem in physiography, and one which has not yet been settled. It is hoped that this occurrence of glacial bowlders will be of some assistance to the next physiographer who undertakes to read the history of the river.

Age of the Atlantosaurus Beds. By WILLIS T. LEE.

THE paper deals with the southern extension of the Atlantosaurus beds along the eastern foothills of the Rocky Mountains into New Mexico, and shows that certain shales in the Canadian Canyon are probably equivalent to these beds. The shales are also traced south and east from their type localities through a new Dinosaur locality and into Oklahoma, where shales, which are apparently the continuation of the Dinosaur beds, contain fossils of Lower Cretaceous type. The observations thus tend to confirm the opinion held by many geologists that the Atlantosaurus beds are of Lower Cretaceous age.

On the Porphyritic Appearance. By ALFRED C. LANE.

THERE are some five different kinds of phenocrysts, or crystals, which may give a porphyritic appearance, viz:

Coarser relics of a previous consolidation.

Crystals whose formation took place during the migration of the igneous magma.

Crystals which were formed early in the process of cooling and

solidification so that their grain continues to increase clear to the center, while later-formed constituents increase only for a shorter distance, their grain thereafter remaining uniform. This porphyritic type will be most obvious at the center of the igneous mass.

Crystals, the conditions (temperature) of whose formation were nearly half way between those obtaining initially in the igneous magma and the country rock. Such crystals will be most conspicuously porphyritic at or near the margin.

Finally there may be crystals, which like the staurolite of schists, are formed by metamorphic actions, of secondary origin, and occur in sediments, and only casually occur in igneous rocks.

Attention is particularly called to the third and fourth classes, the possibility of the existence of which has been almost overlooked, though their possible existence may be readily inferred from inspection of diagrams of the cooling of an intrusive. Certain field observations render their actual existence probable.

The Basal Conglomerate in Lehigh and Northampton Counties, Pennsylvania. By FREDERICK B. PECK, Easton, Pa.

THE term "basal conglomerate," as here used, refers to that lowest member of series of beds, belonging to the Cambrian, which lies uncomformably upon the pre-Cambrian gneisses, but is conformable with the overlying lower Cambrian dolomites. It occurs here, as elsewhere in Pennsylvania and New Jersey, fringing the pre-Cambrian areas. In eastern Northampton county it fails occasionally as a result of faulting. It has a thickness varying from a few feet near Easton to one hundred or possibly several hundred feet at Alburtis, twenty-four miles southwest of Easton.

Petrographically, it is quite variable. At times it is a coarse conglomerate, made up of quartz pebbles, an inch or two in diameter. Frequently it is a medium to fine grained arkose, consisting of about one part feldspar (orthoclase or microcline) to two or three parts quartz, the former usually thoroughly kaolinized, the latter badly crushed, and under the microscope exhibiting an undulating extinction. Other phases of it present a dense bluish or grayish quartzite. It occasionally contains interstratified beds of a very fine-grained argillaceous sandstone with numerous worm borings (scolithus), but as yet no distinctly lower Cambrian fossils have been found. The seemingly uppermost member is a highly ferruginous, almost jaspery

quartzite, which locally contains iron enough to constitute a low-grade ore. From this horizon a considerable amount of iron ore was formerly obtained. The lowest member of the series, in a number of instances, was found to pass by almost imperceptible gradations into the underlying granitoid gneiss, in such a manner as to suggest the decidedly rapid submergence of a deeply weathered Cambrian land mass, with a correspondingly rapid advance of the sea over the same, affording insufficient time either for the thorough sorting of the loose materials already at hand or the bringing in of any considerable amount of sediment from a distance. The entire basal series, representing, as it does, distinctly littoral or at least shallow-water deposits, has a total thickness of only a few hundred feet at the most, and the conditions under which it was deposited must have rapidly changed to those necessary for the deposition of the off-shore and distinctly deep-water sediments represented by the two or three thousand feet of dolomites and the dolomitic limestones, which immediately succeed it.

The series is the northeastern extension of beds which in York county have been called by Walcott "the Hallam quartzite"[1] and is the equivalent of the Hardiston quartzite of Kümmel and Weller[2] in northern New Jersey.

Post-Glacial Time. By A. H. ELFTMAN.

HITHERTO the St. Anthony gorge has been ascribed to the St. Anthony falls, which is regarded as having decreased in height from Fort Snelling to Minneapolis. Several features of the gorge were described, showing that it was formed largely by rapids. The falls did not assume prominence until two miles above Fort Snelling was reached, and they have been increasing in height. Account is taken of the terraces in the Mississippi valley, and the differential uplifts are recognized as affecting this region. The gorge represents a much longer period of time than has been assigned to it. This is further strengthened by the evidence afforded in the postglacial gorge of the St. Croix river.

The Relation between the Keewatin and Laurentide Ice-sheets. By A. H. ELFTMAN.

EVIDENCE was presented to show that the glacial drift of the upper Mississippi river valley was deposited by independent lobes of the

[1] *Bull. U. S. Geol. Surv.*, No. 134, 1897.

[2] *Bull. Geol. Soc. Am.*, Vol. XII, pp. 149 ff.

Keewatin and Laurentide ice-sheets, alternating in their advance and retreat.

A lobe of the Keewatin ice-sheet first invaded this region from the northwest and extended into Iowa and to western Wisconsin. This lobe formed the Kansan drift in Minnesota and the Kansan and pre-Kansan drift further south. Glacial Lake Grantsburg was formed in the upper Saint Croix valley, and for a time had its outlet northward into Lake Superior. The retreat of this ice was followed by a marked interglacial period.

The second great ice invasion, the Iowan, came from the northeast. The Rainy Lake and Lake Superior lobes of the Laurentide ice-sheet extended to western Minnesota, and the latter lobe was deflected southward into Iowa. This ice does not appear to have retreated far beyond the limits of Minnesota, and was followed in this region by a comparatively short interglacial period.

During the third invasion, the Wisconsin, the Minnesota lobe of the Keewatin ice-sheet again advanced from the northwest across central Minnesota into Iowa. At the same time the lobes from the Laurentide ice-sheet advanced southwestward until they reached the northeastern limit of the Minnesota lobe. The final retreat of the three lobes was contemporaneous, forming glacial lakes and numerous moraines. The Keewatin ice-lobe appears to have completely retired from Minnesota slightly before the lobes of the Laurentide ice.

A new mapping of the moraines formed by the various lobes during their final retreat is presented in support of the views advanced.

The movements of the several lobes of the Laurentide ice-sheet present a combination not noticed heretofore. The lobes from Green Bay and Lake Michigan eastward over the Great Lakes show three well-defined advances — the Illinoian, Iowan, and Wisconsin. The Chippewa, Lake Superior, and Rainy Lake lobes show two advances, the Iowan and Wisconsin. The western lobes in Canada, north of Minnesota, show only one advance, the Wisconsin.

It appears that the advance of the northern part of the ice-sheet to the west was much slower than the advance to the south, and the time required for the Laurentide ice-sheet to reach Lake Winnipeg was sufficiently long to allow of two and three advances and retreats in other portions of the ice-sheet.

The Bellefonte, Pa., Section of the Ordovician. By GEORGE L. COLLIE.

THE section described is located at Bellefonte, Pa., the geographical center of the state. It lies in the Nittany valley, a denuded anticline, between the isoclinal Bald Eagle ridge on the northwest and the synclinal Nittany ridge on the southeast.

The rocks dip to the northwest, the dip varying from 8° at the crest of the anticline to 80° and 90° at the top of the section in Bald Eagle ridge. The total thickness of rocks in the section is 6,000 feet, of which 5,000 feet are limestones and 1,000 feet shales. The lithological features of the rocks have been described in detail in the various geological reports of the state, and do not need further description. Little attention has been given to the faunas found in the rocks, and this paper aims in a measure to supply this deficiency.

Four fossiliferous horizons have been recognized in the limestones and two in the shales. The lowest horizon (A^1 of the paper) is 345 feet above the base of the section. It occurs in an oolitic limestone and is but a few inches in thickness. Ophiletas are the most abundant types found, though Murchisonias occur sparingly. The Ophiletas are related chiefly to *O. Complanata*. This indicates the Calciferous age of this horizon.

Between this lowest horizon and the next succeeding horizon (A^2) there are 600 feet of unfossiliferous rocks. Horizon A^2 contains a mixed fauna. Its relationships are in part with the Calciferous, in part with the Quebec, and in part with the Chazy. The most abundant fossil is *Asaphus Marginalis*, a Chazy form in New York. Various species of Ecculiompholus occur, all of which are closely related to forms described by Billings from the Quebec of Canada. *Ribenia Calcifera* and *Ophileta Uniangulata*, typical Calciferous fossils, are found also. Provisionally this horizon is referred to the Calciferous. Above A^2 are 1,200 feet of unfossiliferous rocks before the third horizon A^3 is reached.

Horizon A^3 is characterized by an overlapping of faunas. Stratigraphically speaking, the horizon is Chazy, but it contains few Chazy fossils. The relationships of the fauna are with Canadian and Newfoundland types rather than with those of the interior as represented in New York. The most interesting fossil found is *Bothyurus amplimarginatus*, a form described by Billings from the Calciferous of the Mingon Islands, Gulf of the St. Lawrence. *Macluna Magna*, *M. Affinis*, *M. Acuminata* are common. The mention of these names

gives some idea of the commingling of faunas at this horizon. For the present this horizon is referred to the Chazy. Two thousand feet of unfossiliferous rocks intervene between this horizon and the Trenton horizon, A^4. The total thickness of the exposed Calciferous is about 1,900 feet; of the Chazy, 2,200 feet; of the Trenton, 900 feet.

Unlike the lower horizons, the faunas of A^4 are closely related to those of New York. They need no description in this place, the only unusual form found being a Brougniartia, a homalonotoid trilobite, which is quite common in the shaly limestones at the top of the Lower Trenton. The shales of the section are fossiliferous at the base and again at the top. The intervening beds are not fossiliferous. At the base the characteristic Utica form, *Triarthrus Beckii*, is very common; its vertical range is 300 feet, and this is taken to be the thickness of the Utica shale. The Lorraine shales contain characteristic fossils similar to those found in similar horizons in New York. Not only is there a marked similarity in the fossils, but in the lithological features of the rocks, indicating very similar conditions in the two fields. During the earlier stages of the Ordovician there seems to have been free communication between Pennsylvania and the Canadian provinces. In the later Ordovician this seems to disappear, and direct communication is established with central New York.

The Devonian and Carboniferous of Southwestern New York. By L. C. GLENN.[1]

THE paper is based on work done by the United States Geological Survey, in co-operation with the states of New York and Pennsylvania, in the areal geological mapping of the Olean and Salamanca quadrangles, together with reconnaissance work southward and westward in Pennsylvania.

The oldest rocks exposed are the upper 700 feet of the Chemung, consisting of argillaceous and sandy shales, with the Cuba sandstone as a thin lentil near the bottom. The Wolf Creek conglomerate succeeds the Chemung and is regarded as a lentil marking the base of, and belonging to, the Cattaraugus shale formation. It is a flat pebble conglomerate, quite variable in thickness, but usually thin and inconspicuous, and thins out and disappears westward on the Salamanca quadrangle. Bright red shales first appear within a few feet above the Wolf Creek and with interbedded greenish shales and soft, fine, greenish-

[1] Published by permission of the Director of the U. S. Geological Survey.

gray, micaceous sandstones characterize the next 300 to 350 feet. This red-shale interval constitutes the Cattaraugus formation. In its upper part a second lentil, the Salamanca conglomerate, occurs. It lenses out eastward, but becomes prominent westward in the Salamanca region and is regarded as the same as the Pope Hollow and Panama conglomerates farther west. A third lentil, called the Kilbuck conglomerate by Mr. M. L. Fuller, occurs about 50 to 70 feet above the Salamanca. It is found in the Salamanca region only.

The next formation is the Oswayo, characterized by rusty olive colored, limonitic sandy shale, from 160 to 250 feet thick. Over this the Sub-Olean, or Shenango, conglomerate is found in some areas, usually 20 to 30 feet thick, but apparently cut out in other places, and on the Olean quadrangle losing its conglomeratic character and merging into a sandy shale similar to the Oswayo shale. Over it, when not apparently cut out also, are 30 to 50 feet of Sub-Olean, or Shenango, shale. This is overlaid by the Olean conglomerate, usually massive and round-pebbled, 50 to 90 feet thick. A few feet of thin, rusty, sandy Sharon shale overlies the Olean conglomerate at Rock City.

The shales below the Wolf Creek are Devonian. From the base of the Wolf Creek to the top of the Oswayo a mingling of Devonian and Carboniferous faunas makes it best to designate these rocks, for the present, as Devono-Carboniferous. Above the Oswayo the rocks are regarded as Carboniferous.

The rocks dip 25 to 30 feet per mile slightly west of south. Minor rolls causing local reversals of dip are known to occur.

AUTHOR'S ABSTRACTS OF PAPERS READ AT THE WASHINGTON MEETING OF THE AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE. SECTION E.

Geological Age of the West Indian Volcanic Formations. By J. W. SPENCER.

THE Greater Antilles appear to be nearly devoid of volcanoes. The writer has seen only the remains of one in Jamaica (at Low Layton), and none in Cuba. But there are extensive underlying igneous formations in all these islands. However, in the inner zone of the Caribbean or Windward Islands there are many cones, and beneath these and the outer islands there is an underlying volcanic basement. In such of the outer islands as St. Martin, and better still in Antigua, and in St. Croix one gets some knowledge of the antiquity of the

older eruptive formations. In Guadeloupe the geological records are equally well preserved, on one side, while on the other there are the more recent volcanic cones, which can also be seen in St. Kitts, Statia, Dominica, Martinique, St. Lucia, St. Vincent, etc.

In St. Martin and Antigua the old volcanic basement forms mountains still uncovered by modern cones, as also in St. Croix. The rocks are essentially an andesite in form of both lavas and tuffs. Their surface topography is molded by atmospheric agents into low mountains and valleys. Overlying such a basement in St. Croix and St. Thomas, according to Cleve,[1] there is a conglomerate containing pebbles with Cretaceous fossils. In this region these basement rocks are so dissected that their remains constitute many of the islands of the Virgin group.

But in Antigua and Grande Terre of Guadeloupe the strata overlying the denuded igneous basement is a subaqueous redistributed tuff with some calcareous beds in the upper zone, over which rest conformably the white limestones, a marly deposit containing Oligocene corals and shells.[2] South of the Guadeloupe Archipelago and Monserrat, the outer islands disappear, and the writer is not aware of the occurrence of the early Tertiary limestones remaining so as to leave evidence of the age of the igneous basement, though by its lithological characteristics and the physical features of its ancient surface one can hardly be far astray in concluding that they are of the same age as the similar formations on the islands to the north. In Barbadoes the Oligocene limestones reappear, but here there are no igneous deposits. It thus seems that the whole Caribbean plateau beneath both the volcanic ridges and the limestone islands is underlaid by an igneous formation dating back to the commencement of the Tertiary periods at least, if indeed these rocks are not as old as those of St. Croix, that is, as ancient as the Cretaceous period.

In St. Martin, St. Bartholomew, and Antigua the mountain belts are entirely made up of the denuded rocks of this old igneous formation without a covering mantle. So also, part of Statia, St. Kitts, Monserrat, the southern end of Martinique, portions of St. Lucia, and the southern end of St. Vincent have their surfaces molded out of the ancient igneous accumulations; but elsewhere in these islands, as also

[1] "On the Geology of the Northeastern West India Islands," *Trans. Roy. Swedish Acad. Sc.*, Vol. IX., 1870–71.

[2] See "Geological and Physical Development of the Various Windward Islands," six papers by J. W. SPENCER, in *Quar. Jour. Geol. Soc. Lond.*, Vol. LVII (1901), pp. 409–543, and Vol. LVIII (1902), pp. 341–65.

in Guadeloupe proper and Dominica, they are covered with volcanic materials which constitute more or less of the cones and ridges, rising to a height of 3,000 to 4,000 feet. In these mountainous islands there is not merely a combination of late and ancient eruptive deposits, but there are several formations secondarily derived from the remains of the older basement, and here is room for more study than has been attempted.

The history of one is more or less the history of all of these conical islands. For instance, in Dominica there is the old andesitic rock, overlaid by volcanic breccia or conglomerate. At other points the age of the tuffs cannot at present be assigned, but some of them have been denuded into relatively large valleys, which have been partly refilled with still newer tuff (like that of the Roseau valley), containing an abundance of water-worn pebbles, often arranged in lines among the more angular material. Such may correspond to the early Tertiary subaqueous tufaceous beds of Grand Terre (Guadeloupe). And these beds have been subsequently tilted outward at considerable angles. As in St. Martin and Antigua and Grand Terre, there is nothing to show that there were any mid-Tertiary eruptions when the whole region was somewhat elevated and the denuding agents were molding the surface into rounded outlines. From the corresponding topography in the more volcanic islands, where not surmounted by the modern cones, the impression is left that the volcanic activity of the region was quiescent during much of the Miocene-Pliocene period, before the building up of the cones and ridges, which were constructed at a relatively late date, for we find the sea bed elevated along with these ridges. Thus we find in Statia and in St. Kitts volcanic cones raised by an upward thrust which carried along with it the sea-floor, covered by about thirty feet of marl now forming broken mantles surrounding the cones to elevations of from 400 to 900 feet. Elsewhere, however, we find fragments of a similar formation appearing with the volcanic rocks brought up by a general elevation of the island. These limestone marls contain practically a living fauna, thus showing the elevation to date no farther back than the end of the Pliocene period. Again, there are two series of gravel formations, one of which is older than the coralline strata just mentioned as interbedded with the volcanic ejectamenta; but this gravel formation had its surface greatly denuded before the formation of the marl. Again, both the marl and the gravel have been further subjected to erosion so as to be often left only in broken series. The newer gravel has not been subjected to so

much denudation. The youthful lavas have been seen both in Dominica and St. Kitts beneath the stratified gravel beds, but at present it has not been determined whether they belong to the older or newer series. The lower gravels in their succession correspond in position to the Lafayette of the continent, and the upper gravels to that of the Columbia. The eruption which raised the cones in St. Kitts and Statia, above referred to, appears to have occurred during the subsidence which gave rise to the upper gravels provisionally regarded as the equivalent of the Columbia series — a mid-Pleistocene formation — and the marl beds thus raised rest upon an incoherent bed of volcanic ashes, containing a living fauna. From all facts before the writer it seems that the volcanic ridges owe their origin to volcanic activity which recommenced about the close of the Pliocene period, and that the eruptions have continued with more or less interruption down to the present day; for we find that the cones and ridges have not become so deeply dissected by rains and streams as would be expected, had their growth not been continued more or less continuously from their rebirth at the close of the Pliocene period to the present year of recorded activity.

The Marl-Loess of the Lower Wabash Valley. By M. L. FULLER AND F. G. CLAPP.

THE fine silts bordering the Wabash valley have in the past been correlated with the ordinary loess of the region by many geologists, including Owen, Collett, Wright, Chamberlin, Salisbury, and Leverett. The recent field work of the writers brought out many points of difference in the silts lying respectively above and below the 500-foot contour. The lower type, which we have termed "marl-loess," is coarse and frequently carries as high as 30 per cent. of $CaCO_3$, while the common or upland type carries less than 5 per cent. Numerous exposures of distinctly stratified silts, interbedded in a few instances with pebble layers, were noted. Fossils consisting mainly of land species abound, but are not in general regarded as indigenous, as the perfection of the laminæ in the fossil-bearing layers points to an absence of vegetation during its accumulation, and would indicate — if the deposit were eolian — the probable absence of both moisture and food, the two chief requisites of the molluscan life. Instead of forming a mantle conforming to surface inequalities, as does the upland loess, the marl-loess frequently occurs as extensive flats or broad, gently sloping terraces, usually burying a somewhat rugged

topography. Fossils, stratification, terraces, and silted divides occur at all altitudes below 500 feet, but never above, and although the greater abundance of the marl-loess on the east side of the valley is suggestive of eolian action, the character and range of the features mentioned afford a preponderance of evidence in favor of an aqueous origin of the deposit up to an altitude of 500 feet, or 120 feet above the river. The upland loess is regarded as an eolian derivative of the marl-loess.

The Hanging Valleys of Georgetown, Colo. By W. O. CROSBY.

THE paper describes chiefly the break of several hundred feet between the floor of the valley of Clear Creek and that of one of its principal tributaries, Leavenworth Creek, and explains it as due, not to fluvial or glacial erosion, but to faulting, of which abundant independent evidence is afforded by mining developments. Other and similar features in the vicinity are correlated with this, and it is shown that the part of the main valley occupied by Georgetown is a depressed fault block or *graben*, and that the valley is due, in part, to displacement, and not solely to erosion, suggesting comparison with Yosemite. The idea is also advanced that the elevation of this part of the Colorado Range has been recently, and may be still, in progress, and that, while in the past the movement has been chiefly massive, developing the great fault scarp overlooking the plains, it has, in later time, affected the axis more than the margin of the great orographic block, leading to a marked tilting of the Cretaceous peneplain, and, in part at least, it is very locally differential, and, in the Georgetown instance, in a way to accentuate the topography.

Glacial Features of Lower Michigan. By FRANK LEVERETT.

THIS paper presents results of an investigation of the Pleistocene deposits and features of Michigan carried on for the past three years under the supervision of Professor T. C. Chamberlin, chief of the glacial division of the United States Geological Survey.

Lower Michigan lies within the limits of the latest or Wisconsin drift sheet, but inequalities of earlier drift sheets may have given rise to some of the topographic features and possibly to the strong features, such as basins and the high bordering rims. The high country northwest of the Saginaw basin has 350 to 500 feet or more of drift, while the basin itself has an average of scarcely 100 feet. It seems

doubtful if this difference, with its resulting relief, should be referred wholly to the Wisconsin or last stage of glaciation.

Evidence of distinct ice invasions is found in the northernmost part of the lower peninsula in the constituents of the drift, which are such as to show a movement east of south from the Lake Superior region into the Huron basin, another and probably later movement from the Georgian Bay region southwestward across Michigan and onward to southeastern Iowa, as well as the still later movement referable to the Wisconsin stage of glaciation. A single hill north of the Saginaw basin was found to carry Potsdam sandstone from the Lake Superior region, jasper conglomerate from the Georgian Bay region, and gypsum from the borders of the Saginaw basin. In the western and southern parts of the peninsula, interglacial soils and peat beds are struck in wells, while in the southeastern part striæ, as noted by Sherzer, suggest distinct ice invasions.

The paper discusses the lobing of the Wisconsin ice sheet, the development of a succession of moraines, and the lines of discharge for glacial waters. Attention is also given to drumlins which occur near Charlevoix, and to the eskers in the region covered by the Saginaw lobe.

The drumlins seem to be subglacial accumulations, since they consist of till which is more thoroughly kneaded or worked over than the till of the neighboring moraines. They appear also to have been built up slowly as the ice moved over them, there being traces of lamination concentric with the upper surface of the drumlin. The ice then apparently extended to a strong moraine that passes along the southeast border of the drumlin area.

The eskers of this region are commonly found in shallow valleys, termed "esker troughs," which were cut in the till. This situation, together with the fact that the eskers, like the till, are composed largely of local rocks, strongly favors the view that their material was derived from the till through the agency of subglacial waters.

On the Evidence of Post-Newark Normal Faulting in the Crystalline Rocks of Southwestern New England. By WILLIAM H. HOBBS.

STRUCTURAL work within the belt of crystalline schists of southwestern New England has until recently been carried out upon the assumption that the rocks have been deformed solely by a process of folding. Both Dana and Pumpelly have emphasized this assumption

in their papers upon the geology of the region. The effect of this assumption has been far-reaching and has profoundly affected the mapping during the past twenty years, so that faults have in but few instances been entered upon the maps. The study by the writer in the summer of 1899 of the complexly faulted basin of Newark rocks lying within the Pomperaug valley in Connecticut, and the consideration of the work of others upon the Newark areas to the east and to the southwest of the New England crystalline belt, led inevitably to the conclusion that a system of joints and faults produced in post-Newark time must have been superimposed upon the earlier structures produced by folding, and perhaps by faulting also, within the intermediate belt of crystalline rocks. The problem was then to find means of recognizing these faults within the complexly deformed province. The methods which have been found available are dependent, not so much upon the location of individual faults by the ordinary means, though such methods have not been overlooked, but by the reading of the fault *system* as a whole through the study of the topography, drainage, known formation boundaries, joint system, etc. Five small and widely separated areas were selected in the crystalline belt within each of which a considerable number of formations were found in small masses in juxtaposition. The structure of these areas, while difficult to determine, was found in each case to require only patience and industry, whereas the areas in which formations were found in larger masses by their very simplicity of areal distribution generally allowed several equally adequate explanations.

Briefly to summarize, it may be stated that in all of the areas a system of joints in correspondence with a system of faults was found superimposed upon the older folded structures of the region. The relative importance of deformation by folding and by faulting within the region in question is somewhat difficult to estimate, but it seems probable that the present attitudes of the rocks are at least as largely to be accounted for by the fault structure as by the system of folds.

On a Record of Post-Newark Depression and Subsequent Elevation Preserved in the Crystalline Rocks of New England. By WILLIAM H. HOBBS.

ALONG the course of the Housatonic river, between the townships of Sheffield, Mass., and Salisbury, Conn., is found a somewhat remarkable belt of largely silicified dolomite whose length is not

far from twelve miles and whose breadth varies from a half mile to two miles or more. This somewhat remarkable backbone of rock early attracted the attention of Percival. It is noteworthy for its hummocky structure, but it nowhere rises more than one hundred feet above the general level. Careful study shows that the skeleton-work of silica forms an intricate network which goes out from parallel vertical walls of considerable thickness. These trunk lines or feeders are shown to have the direction of parallel series of vertical joints which had their origin in post-Newark time and were unquestionably conditioned by a compression of the southwestern New England region as a whole. The width of the silica walls forming the feeders and the peculiarities of the silica network lead to the belief that the same process of solution and removal of the dolomite which is now widening joint planes in the area, operated subsequent to the formation of the joint planes and previous to the infiltration of the silica. If it be true that surface conditions operated to widen joint fissures, we must assume a depression of the area until this surface zone came within the belt of cementation, for here only could the infiltration of the silica have obtained, and thus a cycle of depression and elevation of the area within post-Newark times must be supposed.

The Freshwater Tertiaries of Green River, Wyoming. By W. M. DAVIS.

A BRIEF visit to the Tertiary formation of Green River, Wyoming, in the summer of 1902, sufficed to discover many variations of texture in the strata that have usually been regarded as lacustrine. Fine bedded cardboard shales frequently alternate with sandy layers in which cross-bedding and ripple-marks are not uncommon; some of the strata contain small clayey pebbles cemented by calcareous material, and closely resembling certain specimens of "tepetate" brought from Mexico by R. T. Hill. It is believed that so great a variation of texture is inconsistent with the generally accepted theory that the Green River formation was deposited in a large and deep lake. The deposits are better accounted for by deposition in a variable shallow lake, possibly alternating from time to time with subaërial or fluviatile conditions.

The Basin Ranges of Utah and Nevada. By W. M. DAVIS.

SEVERAL mountain ranges in the Great Basin of Utah and Nevada, examined in the summer of 1902, are believed to be faulted blocks,

progressively displaced from late Tertiary to the present time, and maturely carved by contemporaneous erosion. The evidence for this conclusion is not structural, but physiographic. The base line of the ranges is of gentle curvature, unrelated to the mountain structure. The ravines by which the ranges are often dissected are narrow and steep-walled to their very mouths. The spurs between the ravines are often truncated systematically in a triangular facet at the mountain base. All these features are necessary results of progressive faulting and contemporary erosion, while they are not explainable on the theory that the ranges are residuals of much larger masses, unrelated to faulting.

The Blue Ridge in Southern Virginia and North Carolina. By W. M. DAVIS.

A RECENT visit to southern Virginia and North Carolina brought clearly to my attention what many students of that region must know already, but what is certainly unknown to geographers in general, namely, that the Blue Ridge is there not a ridge in any proper sense of the word, but a southeast facing escarpment. The escarpment is not due to any persistent rock structure, but results from the reduction of the land surface to a relatively low level by the headwaters of the short Atlantic rivers, whose drainage area therefore underlies that of the larger west-flowing rivers of the Mississippi system. The escarpment occurs where the Atlantic streams are undercutting the uplands of the Mississippi system. Residual mountains rise over the rolling uplands of the Atlantic rivers and over the rolling highlands of the Mississippi river: Kings and Pilot mountains are examples of the first, and Mount Mitchell and Roan mountain of the second. Grandfather mountain stands on the escarpment.

The Protection of Terraces in the Upper Connecticut Valley. By C. H. HITCHCOCK.

THE conclusions derived after many years of study relative to the origin of the Connecticut river terraces north of Massachusetts are as follows: (1) The higher terraces are part of a flood-plain deposited by the waters derived from the melting of the ice-sheet. (2) A differential depression of level amounting to about one and one-fourth feet to the mile in proceeding northerly greatly diminished the velocity of the current, so that the material is much finer than it would have been

had the southerly slope been the same as now. For example, at the Wells river, Vermont, the altitude of the river is now 407 feet above tide; but anciently it was 356 feet. The highest terrace is now 630 feet; formerly it is estimated to have been 373 feet, a fall of 257 feet. The reduction of the descent was from 2 to 1.4 feet to the mile. (3) The carving of the greater terraces was effected while the land was resuming its present level — probably lower than its original altitude. (4) The lower terraces and the intervals were formed later.

The following features were not clearly understood: (1) Why should the terraces upon the opposite sides of the valley commonly vary in numbers, altitude, and bulk? (2) Why are the deltas of the tributaries so often higher than the normal flood plain? (3) Why should the number of the terraces of the tributaries so often exceed those of the main stream, their upper surfaces being the same? These queries may be answered partly by assuming that the flood plain was not entirely filled out and that the tributary may often have had an extraordinary volume, bringing down a disproportionate amount of sediment. But there remained this problem: Why is there such a great irregularity in the altitudes and number of the lower terraces?

A better understanding of this subject has been afforded by the recent paper of Professor W. M. Davis,[1] who applies to the solution of the problem the theory of Hugh Miller the younger. Miller recognizes a slow regional uplift while the river wears away the accumulated sediment, and ascribes the presence of each lower terrace to a species of protection afforded by such obstacles as ledges and till, as the degrading river swings laterally to lower and lower levels. At the Westfield locality the presence and altitude of every terrace are clearly shown to be due to this cause. The simplicity of this explanation causes one to wonder why it had not been understood earlier. I have applied it extensively the past season to the modified drift of the upper Connecticut and adjacent streams and found it very generally acceptable; in fact, its well nigh universal adaptation became quite monotonous. Diagrams were prepared to show how the terraces had been protected over an area fifteen miles long in the neighborhood of White River Junction and Hanover. The villages of Hartford, Wilder, and Hanover occupy such protected situations. Between East Hartford and Wilder an esker with underlying stiff clays has assisted in the preservation of the ancient flood plain. In Haverhill, thirty miles northerly, the absence

[1] "The Terraces of the Westfield River, Massachusetts," *American Journal of Science*, Vol. XIV (August, 1902).

of protection seems to have led to the extensive scouring out of the valley, and for that reason the interval is unusually broad. Elsewhere it was observed that tributary streams have cut across the higher terraces, whose exposed scarps remain in spite of the absence of any protecting underlying ledges.

Shore Phenomena on Lake Huron. By M. S. W. JEFFERSON.

KINCARDINE, Ontario, is nearly one hundred miles north of Port Huron, on the east shore of Lake Huron. As the shores there are

BEACH CUSPS IN LAKE HURON.

undergoing uplift, there is an interesting contrast with geographic conditions south of Gilbert's isobase, as at Muskegon, Lake Michigan. There a line of dunes margins the "Big Lake," standing on a bar which almost closes the river mouth, that expands behind into a considerable lake, and is marshy, with typical drowned-character for

miles back. At Kincardine and similar points the bar and ancient lagoon behind it are now high and dry. The sand bar south of the old entrance serves the town for a cemetery. The basin behind is drained by the palmate branches of the Penetangore, which have all cut deep, young valleys in which they rush along over beds of stony waste. The lowest reach of the river serves, like Forel's plemyramêtre on Lake Geneva, to show the Lake or Harbor seiches, by alternate down and reversed flow of the river. Elevated beaches under bluffs in till occur on the lakeward side to the north and south.

The shore and the immense dunes in the southern region at Holland, Muskegon, Pentwater, or Ludington, are all of the finest sand, which only the strong west winds save from the lake as the land settles down. To the northward at Kincardine the rising of the land brings continuous new levels of the till into the play of the waves, which pick out pebbles and bowlders to line a beach on which sands make only patches, and where the dunes are of but moderate significance, since the sand supply is small. Petowsky, also north of the isobase, on Lake Michigan shows a similar beach.

Studies continued from Lynn, 1898, to Martha's Vineyard, 1901, show the beach cusps to be component features of a *beach ridge*, prominent on the tideless Great Lakes, and faint but recognizable on the ocean. Cusps are found at numerous points on the lakes, are always developed with abating surf or off-shore winds, with an interval that bears some proportion to the strength of the waves, often having three-foot spaces at Kincardine and eighty on the ocean. The ridge is often without cusps; has at times been seen and photographed with water caught behind and rushing out at breaks in the line, as with the weed line at Lynn; and at times grades from continuity to regions of perfect cusps. The cusps seem related to a long-shore current, their precise cause not being evident. The cross waves noted by Bramer, 1898, were seen habitually at every point, and photographed, but were not seen to be accompanied by cusps, nor were the numerous cusps observed and photographed seen to associate with such cross-waves.

Land and sea breezes were observed; the small deflagration wrought by blown sand on rock-material; and the small dimensions of Lake waves that seriously endangered shipping.

Valley Loess and the Fossil Man of Lansing, Kan. By WARREN UPHAM, St. Paul, Minn.

THE loess in the Missouri and Mississippi valleys is attributed to deposition by these rivers during a time of somewhat lower altitude of

this region, at the beginning of the Champlain epoch, when the glaciated area of this continent sank from its previously high elevation to be mostly 300 to 500 feet lower than now. By this depression a temperate climate was restored on the border of the continental ice-sheet, which became greatly reduced by its surface melting, so that much of the drift before contained within the ice was at last exposed on the thinned ice-fields, as now on the Malaspina ice-sheet in Alaska.

The ice-melting and rains probably swelled these great rivers to twice or three times their present average annual volume; and their supply of silt, brought in abundance by the rills, brooks, and rivers that flowed down from the waning ice-sheet, was very probably fivefold to tenfold more than now. Under these conditions of very abundant silt, rivers swollen to floods throughout the summers, and less current of their sluggish descent to the Gulf, it is estimated that the Iowan stage of chief deposition of the valley loess, gradually building up the river flood plains to heights of 150 to 250 feet above the bottom lands of today, may have occupied only about a thousand years.

During the same time the winds are thought to have blown away much of the loess from the valley flood plains, and from the ice surface, spreading it far and wide as the general sheet of upland loess, mostly 10 to 25 feet thick, mantling the high and low lands upon the great areas between the rivers with a surprising uniformity of thickness. It is evident, also, that this silt mantle includes some contribution, most considerable westward, of wind-borne dust from the great western plains, this part not being of glacial origin.

After the accumulation of the loess, and before the moraine-forming Wisconsin stage of the waning and wavering glaciation, this region was uplifted 300 to 500 feet, or perhaps somewhat more, on account of the diminution of the ice weight and pressure, thereby giving to the rivers the same steeper gradients and more powerful currents as now. They therefore eroded the valley loess to depths somewhat below the present bottom lands, and sculptured the valleys in nearly their present forms, with high inclosing bluffs of loess, before the moraines of Wisconsin, Minnesota, and northern Iowa, were amassed along the ice boundary at pauses of its general retreat.

Again, during this Wisconsin stage much modified drift was borne into the valleys. Its coarser portion of gravel and sand filled the valleys anew to heights of 100 to 200 feet, or more, near the ice border; but the strong river currents, with nearly their present slopes, carried the fine silt, corresponding to the former loess deposit, far down the valleys to the lower Mississippi and the Gulf.

Along the Big Sioux Valley, on the northwest boundary of Iowa, a flood plain of modified drift associated with the moraines has an average width of one and a half miles, as described in Vol. X of the Iowa Geological Survey, and is only about 10 feet above the present relatively insignificant bottom land, which averages about a fifth of a mile in width. Below the junction of the Big Sioux with the Missouri, this flood plain of Wisconsin time continues with a width of 6 to 12 miles on the east side of the Missouri through the distance of 90 miles to Council Bluffs and Omaha, having only the same slight altitude above the river. Southward from the mouth of the Platte river, as I think, the old Wisconsin flood-plain was lower than the bottomland today, which has gained in thickness, rather than lost, ever since the Ice age. Conditions requisite for silt deposition 30 to 50 feet above the Missouri at Lansing, Kan., where a skeleton was discovered last February under 20 feet of a deposit, which I regard as the original Iowan loess, appear thus not to have existed during the ensuing Wisconsin stage of glaciation, nor during any part of the Postglacial period.

The antiquity of the Lansing man is, I think, to be measured by about 12,000 years, or, at the longest, 15,000 years. But men are known to have been living in Europe, and very probably they may also have migrated to America, in the early part of the Ice age, or even before it, that is, very surely as long age as 100,000 years. Therefore the resemblance of the Lansing skeleton to the average type of our American aborigines, called Indians, appears in no degree surprising to one who believes that the creation of plants and animals has proceeded by the gradual methods of generic and specific development which are collectively termed evolution.

History of the Caribbean Islands from a Petrographic Point of View. By Dr. Persifor Frazer.

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Our knowledge of the geological history of the Antilles is still very imperfect. Among the most important parts of the bibliography of this subject are:

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Reconstruction of the Antillean Continent, by J. W. Spencer, *Bull. G. S. A.*, August 14, 1894.

Geographical Evolution of Cuba, by J. W. Spencer, *ibid.*, December 27, 1894.

Zur Geologie von San Domingo, by W. Bergt, Abhandlung der naturw. Gessell. "Isis" in Dresden, 1897.

Cuba and Porto Rico, with the Other Islands of the West Indies, by Robert T. Hill. New York: The Century Co., 1898.

This last work is a compendium of information on the subject and contains an extensive bibliography of the less scientific and more descriptive treatises on the West Indies.

At the Bath meeting of the B. A. A. S. in 1888 I presented numerous rock specimens and thin sections cut from them illustrating a region of about forty miles around Santiago de Cuba. The rocks were partly eruptives and partly clastic, but almost all exhibited profound alteration. The thin sections from these eruptives were examined with me by Dr. Hensoldt, Mr. Kunz, and Mr. Lacroix in this country, and later by Mr. Teall, Mr. Rudler, the Abbé Renard, Professor Judd, and the lamented Professor George H. Williams in London; all of whom were practically agreed as to the main constituents.

The specimens were divided into:

A. Those from the hills containing the West mine of the Jurugua Iron Co. near Firmeza: (1) diorites, some of which contained much altered hornblende and viridite (chlorite), the thin slides filled with microlites and the rocks traversed by epidote veins; (2) dolerites (gabbros) with chloritic groundmass, magnetite, rods of feldspar, and some olivine.

B. From the hills southeast of that in which the East mine was located and about fifteen miles northeast of Santiago de Cuba: (1) garnet rocks with iron ore (sp. gravity 3.962); (2) fibrous actinolite and brown iron oxides partially altered to an epidotic mass; (3) iron ores (some showing cross lines like the Widmanstätten figures in meteoric iron).

C. From the Sietes Altarés, about thirty-five miles east of San-

tiago de Cuba: orthofelsite porphyry (rhyolites) like those erroneously referred to by the late Professor H. D. Rogers as "jasper," and later recognized by the late Dr. T. Sterry Hunt as a mixture to which he gave the general name "orthophyre," also like the Arvonian tuffs of Hicks near St. David's Head, Pembrokeshire, Wales.

D. The specimens from the region of the La Plata mines were quartzites containing hornblende, iron ores, and among the incidental minerals a claret-red garnet.

In the area described were found upon or associated with the eruptives sandstones, conglomerates and crystalline limestones, laminated iron ores with masses of pyrite not yet converted into the latter. The alteration of the areas of contact in these rocks by the more recent diorite dykes which cut them was evident.

From the zoölogical and geological researches of Alexander Agassiz in Caribbean and Mexican waters, and the careful studies by Gabb, Crosby, Spencer, and Hill, the probability of very great changes of level in the Antilles since the close of the Cretaceous period is fortified by several different lines of proof, *i. e.*, the ledges and shelves of the island borders, the wide distribution of the white radiolarian limestones, etc. Professor Crosby pointed out orographic reasons for assuming a former "bridge" (*i. e.*, causeway) between the greater and lesser Antilles. As he says, the mountains of "the northern arm of the island of San Domingo pointing toward Cape Maysi on Cuba," and the northern range in Cuba "regains the western trend and points directly toward Yucatan." He also alludes in his paper of December 13, 1882, to the "axis of old eruptive rocks," of which, so far as he has been able to learn, "each member of the group consists." He does not give his authority for the fact, nor say to what age he ascribes these eruptives; but if he contemplated the possibility of this age being pre-Cambrian, he anticipated by six years two of the strongest reasons I adduced for belief in the physical continuity of the great and little Antilles, and the present exposure of parts of the nucleus which are of great age and possibly have never been very deeply covered by sedimentary rocks.

His observation that this nucleus is flanked on either side by schists and slates I have confirmed, and I have been tempted to class these with the damourites of the Appalachians, and the feldspar porphyry (rhyolites), with the Arvonian tuffs of South Wales.

[1] *Zur Geologie von San Domingo.* Abh. der naturw. Gesel. "Isis" in Dresden, 1897, Heft II, p. 64).

It is gratifying to find that Dr. W. Bergt supports unreservedly the Archean age of the nucleal axes of the Caribbean islands in the following words:[1]

> Das archäische Alter, welches, P. Frazer für die Centralketten des südöstlichen Cuba feststellen konnte, und das er für ganz Jamaika, für San Domingo, Puerto Rico, und die Windwardinseln vèrmuthete, kann nunmehr bestimmter für San Domingo angenommen werden.

It may be, as Mr. Hill suggests, that no "Paleozoic nucleal rocks" have been established with certainty in "Cuba and Santo Domingo" or any other of the border lands of the "American Mediterranean" (*Cuba and Porto Rico*, p. 384) although de Castro imagined he had discovered such near Cienfuegos, yet this fact would not invalidate the evidence that part of these nucleal rocks are pre-Cambrian.

And one purpose of this paper is to recall the fact that we have proofs of physical connection with the western continent of these outlying islands not only from the physiographic features, drowned valleys, submerged plateaus, trend of conformation through the major axes of the present detached islands, paleontological analogy with South American forms of life, etc., but, in addition to all these, the close petrographical relationships of the crystallized and crystalline rocks and their congeners with those of the main land.

The island of Cuba seems to be constructed of an original igneous mass, diorite, on which clastic rocks, including mica-schists which may be Paleozoic, and sandstones and limestones of Mesozoic and recent ages, are deposited without apparent effects of metamorphism. Through all these are veins of newer eruptives which have generally altered the rocks they have fissured, *i. e.*, giving crystalline character to the radiolarian limestones lifted since Cretaceous time out of the adjacent seas, producing magnetite in the iron-oxides derived in part from the pyrite, changing to quartzites the siliceous slates, etc.

The lithological character, great alteration, complexity of the series, analogies in paragenesis and alteration-products with rocks of Archean areas in various distant parts of the earth's surface, and the physiographic relations of the greater and lesser Antilles to the peninsula of Yucatan and to Venezuela, suggest a physical connection with the South American continent, and a former American Mediterranean (Caribbean) sea.

These conclusions are in harmony with those of Professor Crosby, Professor J. W. Spencer, and Mr. R. T. Hill, and are specifically confirmed by Dr. Bergt (*supra*). They constitute a reinforcement of the

results arrived at by geotectonal, through petrographic, considerations, in the attempt to retrace the geological history of the West Indies.

A paper received December 27, from Dr. Callaway presents in the description of the structure of the island of Anglesey a remarkable parallel with that of the island of Cuba.[1]

Some Results of the Late Minnesota Geological Survey. By N. H. WINCHELL.

THIS paper mentioned some of the scientific conclusions and some of the known economic results reached by the survey, presented in the final report. Among the scientific conclusions have been: the definition of the parts of the Upper Cambrian in the upper Mississippi valley; the identification of the Potsdam sandstone as seen at Potsdam, N. Y., with a quartzitic sandstone which was found to be a part of the Keweenawan; the definition of the Lower Silurian and its parts; the determination of the eastern extent of the Cretaceous; the discovery and announcement of the duality of the ice-epochs; the determination of the length of time elapsed since the last (or Wisconsin) ice-epoch, through the recession of the falls of St. Anthony; the formation of glacial lakes about the ice-border; the origin of kames (now called eskers) in ice-walled gorges; the superglacial position of the drift while being transported, especially in proximity to the ice-margin; the duality of the iron-bearing formations in the Lake Superior region, and the later discovery of a third horizon; the separation of the Archean *en masse* into two non-conformable parts, viz., the upper and the lower Keewatin, with a great basal conglomerate between them; the detection of the oldest known rock in the Lake Superior region (the greenstones called *Kawishiwin*), the supposed earliest crust of the globe; the origin of the Mesabi ores in a greensand which has been altered, affording iron oxide by concentration; the contemporary deposition of oceanic silica from solution; the original greensand, and pebbles and breccia associated with it, as well as sheets of basic lava of the same date, were of volcanic origin; the well-known jaspilytes of both Mesabi and Vermilion ranges were originally the result of silification of volcanic obsidian (supplementary to the hypothesis of Wadsworth), but sometimes were broken and distributed so as to constitute secondary jaspilyte beds; the formation of

[1] "Plutonic complex of Central Anglesey," *Quarterly Journal of the Geological Society*, Vol. LVIII (November, 1902).

sedimentary jaspilyte from the chemical precipitation of silica, this grading into other sedimentary rocks; the derivation of the granites of the Archean from metamorphism and fusion of Archean sediments; the supposed origin of the alkaline quality of these first sediments being in the atmosphere, as the basal crust could not have afforded them; the derivation, in the same manner, of the gabbro and associated basic igneous rocks, from the metamorphism and fusion of the greenstones with their clastic variations; the addition of a large number of minerals to the known mineralogy of Minnesota.

Of economic and educational results the following were mentioned: the discovery of the cause of foul water in common wells in the prairie region of Minnesota, and the suggestion of effective remedies; the discovery, through a series of physical tests, of the excellence of the Hinckley sandstone, now widely used under the name "Kettle River stone." The existence and position of the Mesabi range, as distinct from the Vermilion range, was pointed out in 1884. This was followed by explorations which resulted in the first discovery of important bodies of ore on that range.

"But notwithstanding the scientific discoveries of the Minnesota survey, and over and above all its aid rendered to economic interests, it is probable that the most valuable service it has rendered to geology consists in this: The illustration it has given of the establishment of a state geological survey by the state legislature and the intrusting of the same to the state's university. It is not an uncommon thing now, but when the Minnesota survey was submitted to the board of regents of the state university, it was a novel and unheard-of proceeding, and its progress was scrutinized closely by the authorities of other states. The original law was carried out without a single change. The plan of progress and of the report which was adopted the first year of the survey was faithfully carried out to completion and without a single interruption, lasting a period of twenty-eight years, *i. e.*, from 1872 to 1900."

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